NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-778

Solar Radiation Pressure Effects on the Helios Spacecraft

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JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
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Solar Radiation Pressure Effects on the Helios Spacecraft

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PREFACE

The work described in this report was performed by the Mission Analysis Division of the Jet Propulsion Laboratory.

ACKNOWLEDGEMENT

The author wishes to express his gratitude to Jens Peyn of the University of Hamburg, West Germany, for a detailed analysis of the solar radiation force acting on the high-gain antenna of the spacecraft and other structures and for his help in the preparation of the Helios solar radiation force computer programme.

CONTENTS

ABSTRACT

The improved and completed mathematical model of the solar radiation force and torques, which has been previously developed for the Mariner 10 Venus/Mercury spacecraft mission, is used for a detailed analysis of the effects of the solar light pressure on the Helios spacecraft. Due to the fact that the main body of the Helios spacecraft is a surface of enclosure, inside of which most of the reradiated thermal energy is lost, expressions for the portion of the solar radiation force, produced by the thermal reradiation, had to be given a different form. Hence the need for the derivation of a somewhat different theoretical model for the force acting on the main body of the spacecraft.

I. INTRODUCTION

The heliocentric orbit of the Helios spacecraft is an extended ellipse of eccentrictiy 0.54*. After the injection into its orbit at its aphelion point at approximately one astronomical unit from the Sun, the spacecraft is falling freely toward the Sun until it reaches its perihelion point at approximately 0.3 astronomical units from the Sun. It moves in the orbital plane of the Earth (ecliptic plane) with an orbital period of approximately 180 days.

The proximity of the spacecraft to the Sun in the region of its orbit near its perihelion point causes a relatively large effect of the solar radiation force on the reflecting surfaces of the spacecraft, thus creating a necessity for a detailed analysis of the effects of the solar pressure on the orbital motion of Helios. The mathematical and physical concepts of the model, used in this analysis, are essentially the same as those outlined in References 1 through 6.

The side view of the Helios spacecraft is shown in Figure 1. The principal parts of the spacecraft are: 1) the main body of the spacecraft, consisting of two truncated cones, connected by a circular cylinder in the middle; 2) three antennae: high-, medium-, and low-gain antenna, and 3) four booms carrying instruments. More detailed side and top views of Helios are shown on Figures 2 and 3.

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*Numerical values used throughout this report are for Helios A spacecraft.

The mathematical model for the solar radiation force will be given in the form of a short outline. In addition to this, particular attention will be paid to the derivation of the expression for the thermal reradiation of the absorbed solar energy, emanated from the relatively large surface of enclosure of the main body of the spacecraft.

Since the spacecraft is rotating at 60 rpm, the most suitable reference system, which will be used for the calculation of the solar radiation force, is an inertial ecliptic system, translated into the center of mass of the spacecraft.

II. THE SOLAR RADIATION FORCE

The solar radiation force acting on the spacecraft is the sum of solar radiation force acting on one particular component of the spacecraft, and is given by (Reference 1)

$$\bar{F} = -\frac{\lambda_s}{\rho^2} \iint_S [f(\theta)\bar{N} + (1 - \beta\gamma)\ \bar{U} \cos\theta]\ dS, \tag{1}$$

where

$$f(\theta) = 2\ \beta\gamma\cos^2\theta + B(f)\ [\gamma(1 - \beta) + (1 - \gamma)\ K(r, \theta)]\ \cos\theta \tag{2}$$

Here $\lambda_s = 4.51312 \times 10^{-6}\ N/m^2$ is the solar constant, ρ is the heliocentric distance of the spacecraft, expressed in astronomical units, θ is the local angle of incidence, $\bar{N}$ is the unit vector along the local normal to the irradiated surface, $\bar{U}$ is the unit vector along the spacecraft-Sun direction, $B(f)$ is the diffuse reflection coefficient, γ is the total reflection coefficient and β is the specular reflection coefficient of the illuminated surface. If Lambert's

cosine law of diffuse reflection is used,

$$B(f) = \frac{2}{3}.$$

S is the irradiated surface area of the spacecraft's component, and $K(r, \theta)$ is the thermal reradiation function. From References 1 and 9, the explicit expression for $K(r, \theta)$ is

$$K(r, \theta) = \frac{\varepsilon_F T_F^4 - \varepsilon_B T_B^4}{\varepsilon_F T_F^4 + \varepsilon_B T_B^4} \qquad (3)$$

in the case when both spacecraft's components are exposed to space. T_F and T_B are respectively absolute temperatures and ε_F and ε_B emissivities of the front (illuminated) and back surfaces of the spacecraft's component. From the balance between the total absorbed solar energy and the amount of energy reradiated from both surfaces of a piecewise slab structure, using Gauss' theorem and assuming that the areas of the front and back surfaces are the same, we have

$$\varepsilon_F T_F^4 + \varepsilon_B T_B^4 = \frac{K_s (1 - \gamma)}{\sigma \rho^2} \cos\theta \ , \qquad (4)$$

where σ is the Stefan's constant

$$\sigma = 5.6697 \times 10^{-8} \text{ kg/sec}^3 \ {}^\circ\text{K}^4 \ ,$$

and

$$K_s = 1.353 \times 10^3 \text{ kg/sec}^3.$$

For an elementary slab of thickness ℓ, Laplace's equation and boundary conditions yield

$$T_F = T_B + \frac{\sigma\ \varepsilon_B \ell}{k} T_B^{\ 4} \quad , \tag{5}$$

where k is the thermal conductivity of the material. Equations (4) and (5) yield

$$K(r_1\theta) = 1 - \frac{2k\rho^2\ \sec\theta}{K_s\ \ell(1 - \gamma)} (T_F - T_B) \quad ; \tag{6}$$

this expression is linear with respect to the difference of absolute temperatures of the front and back sides.

For surfaces of enclosure the absorbed thermal energy which is reradiated inside the body is multiply scattered in all directions, since the interior of the surface contains various parts of different shapes. The so-scattered particles lose their momentum and only an insignificant small portion is reradiated outside. Thus, the expression for $K(r,\theta)$ becomes

$$K(r,\theta) = \frac{\varepsilon_F\ T_F^{\ 4}}{\varepsilon_F\ T_F^{\ 4} + \varepsilon_B\ T_B^{\ 4}} \tag{7}$$

where, as before, T_F and T_B have to be determined from Equations (4) and (5).

Finally, for adiabatic surfaces,

$$K(r,\theta) = 1.$$

For surfaces for which $T_F = T_B$ (no temperature gradient),

$$K(r,\theta) = K = \frac{\varepsilon_F - \varepsilon_B}{\varepsilon_F + \varepsilon_B} \tag{8}$$

III. EXPANSION OF THE THERMAL RERADIATION FUNCTION K(r,θ) FOR THE MAIN BODY OF THE SPACECRAFT.

The main body of the Helios spacecraft is a surface of enclosure inside of which the multiply scattered radiation is lost. Following the procedure in Reference 1 we can expand the function $K(r,\theta)$ in the following manner. First we write the approximate expression for the temperature ratio

$$\frac{T_F}{T_B} = 1 + \frac{AR(r,\theta)}{1 + BR(r,\theta)} = \frac{1 + (A + B)\ R(r,\theta)}{1 + BR(r,\theta)}$$

where

$$\left.\begin{aligned} R(r,\theta) &= \left(\frac{\cos\theta}{\rho^2}\right)^{3/4} , \\ A &= \frac{\sigma \ell\ \varepsilon_B}{k}\ (T^*)^3 , \\ B &= \frac{3\varepsilon_F}{\varepsilon_F + \varepsilon_B}\ A , \\ T^* &= \sqrt[4]{\frac{K_s(1 - \gamma)}{\sigma(\varepsilon_F + \varepsilon_B)}} \end{aligned}\right\} \tag{9}$$

Further expansion of the temperature ratio leads to the following expression

$$\left(\frac{T_F}{T_B}\right)^4 = 1 + 4AR(r,\theta) + 2A\ (3A - 2B)\ [R(r,\theta)]^2 \tag{10}$$

where

$$3A - 2B = -3A \frac{\varepsilon_F - \varepsilon_B}{\varepsilon_F + \varepsilon_B} = -3AK.$$

Denoting by

$$K_1 = \frac{\varepsilon_F}{\varepsilon_F + \varepsilon_B}$$

we obtain from Equation (7) the approximate expression

$$K(r,\theta) = K_1 + PR(r,\theta) + [R(r,\theta)]^2$$

or, explicitly,

$$K(r,\theta) = K_1 + P\left(\frac{\cos\theta}{\rho^2}\right)^{3/4} + Q\left(\frac{\cos\theta}{\rho^2}\right)^{3/2}, \tag{11}$$

where

$$\left.\begin{aligned} P &= \frac{4\varepsilon_F\,\varepsilon_B}{(\varepsilon_F + \varepsilon_B)^2}\,A, \\ Q &= -\,2\varepsilon_F\,\varepsilon_B\,\frac{11\varepsilon_F - 3\varepsilon_B}{(\varepsilon_F + \varepsilon_B)^3}\,A^2 \end{aligned}\right\} \tag{12}$$

IV. SOLAR RADIATION FORCE ON THE MAIN BODY OF THE SPACECRAFT

The main body of Helios, whose side and top views are shown in Figure 4, consists of two truncated, sixteen-sided pyramids, connected in the middle by a sixteen-sided prism. On account of the very fast spinning rate of Helios, we

shall considerably simplify our calculations if we approximate the body of Helios by two truncated cones, connected in the middle by a circular cylinder. The average radii of the truncated cones are calcualted in such a manner that the areas, which play a major role in the expressions for the solar pressure effects, are preserved. In other words the radii are calculated so that the area of one truncated pyramid is equal to the area of one truncated cone, and the same rule is used for the cylinder in the middle. Thus, for the larger radius of the frustrum we obtain

$$R_1 = 1.372 \text{ m} ,$$

and for the smaller radius which, at the same time is the radius of the middle cylinder, we find

$$R_2 = 0.871 \text{ m}$$

(see Figure 5). The height of one of the frustrums is H = 78.65 cm, and the height of the middle cylinder is h = 55.0 cm.

In order to facilitate the calculation of the solar radiation force acting on the main body of the spacecraft, we shall introduce a noninertial, slowly rotating ecliptic reference frame $x_1\ y_1\ z_1$. The z_1-axis is pointing toward the north pole of the ecliptic, $x_1\ y_1$-plane is the ecliptic plane, and the y_1-axis lies along the instantaneous spacecraft-Sun direction. Incidentally, we should mention that, without any significant loss in accuracy, we can assume that the z_1-axis is also the spin-axis of the spacecraft.

In the $x_1\ y_1\ z_1$ system the equation of the conic surface is

$$\phi(x_1, y_1, z_1) \equiv x_1^2 + y_1^2 - (z_1 + \xi)^2 \tan^2\alpha , \tag{13}$$

where

$$\xi = \frac{R_2 H}{R_1 - R_2} - \frac{h}{2}$$

is the z-coordinate of the vortex of the cone. Hence, the unit vector along the local normal to the surface is

$$\bar{N} = \frac{\nabla\phi}{|\nabla\phi|} = \frac{\cos\alpha}{z_1 + \xi} \begin{pmatrix} x_1 \cot\alpha \\ y_1 \cot\alpha \\ -(z_1 + \xi) \tan\alpha \end{pmatrix}$$

where α is the cone angle, given by

$$\tan\alpha = \frac{R_1 - R_2}{H}$$

or $\alpha = 32\overset{\circ}{.}75$.

Introducing cylindrical coordinates r_1, λ by

$$x_1 = r_1 \cos\lambda \quad ,$$
$$y_1 = r_1 \sin\lambda \quad ,$$
$$r_1 = (z_1 + \xi) \tan\alpha$$

we obtain

$$\bar{N} = \begin{pmatrix} \cos\lambda \cos\alpha \\ \sin\lambda \cos\alpha \\ -\sin\alpha \end{pmatrix} \tag{14}$$

Also,

$$\bar{U} = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} ,$$

and

$$ds = \frac{r_1 \, dr_1 \, d\lambda}{\sin\alpha} ,$$

Since the main body of the spacecraft is perfectly symmetrical with respect to the three coordinate axes, the only existing component of the solar radiation force will act along the y_1-axis. Integrating Equation (1) we obtain the y_1-component of the force acting on both frustrums in the form

$$\begin{aligned} F_{YF} = & -\frac{2\lambda_s H}{3\rho^2} (R_1 + R_2) \Big\{ 4\beta_F \gamma_F \cos^2\alpha + \frac{\pi}{2} [\gamma_F (1 - \beta_F) \\ & + (1 - \gamma_F) K_F] \cos\alpha + 3(1 - \beta_F \gamma_F) + (1 - \gamma_F) \frac{P_F (\cos\alpha)^{7/4}}{\rho^{3/2}} I_1 \\ & + (1 - \gamma_F) \frac{Q_F (\cos\alpha)^{5/2}}{\rho^3} I_2 \Big\} \end{aligned} \quad (15)$$

where β_F, γ_F, P_F, Q_F, K_F are values of β, γ, P, Q and K for the two frustrums. I_1 and I_2 are given by

$$I_1 = \int_0^{\pi} (\sin\lambda)^{11/4} \, d\lambda, \qquad I_2 = \int_0^{\pi} (\sin\lambda)^{7/2} \, d\lambda ,$$

or, in terms of beta and gamma functions (Reference 10),

$$I_1 = 2^{11/4} B(\tfrac{15}{8}, \tfrac{15}{8}) = 2^{11/4} \frac{\Gamma^2 (\frac{15}{8})}{\Gamma (\frac{15}{4})} = 1.382638 \quad ,$$

$$I_2 = 2^{7/2} B(\tfrac{9}{4}, \tfrac{9}{4}) = 2^{7/2} \frac{\Gamma^2 (\frac{9}{4})}{\Gamma (\frac{9}{2})} = 1.248598 \quad .$$

The complete integrated expression for the y_1-component of the solar radiation force acting on the surface of the middle circular cylinder can be taken from Reference 6. It is

$$F_{YC} = - \frac{2\Lambda_s R_2 h}{3\rho^2} \left\{ 4\beta_c \gamma_c + \frac{\pi}{2} [\gamma_c (1 - \beta_c) + (1 - \gamma_c) K_c] \right. \tag{16}$$
$$\left. + 3(1 - \beta_c \gamma_c) + (1 - \gamma_c) \left(\frac{I_1 P_c}{\rho^{3/2}} + \frac{I_2 Q_c}{\rho^3} \right) \right\} \quad ,$$

where β_c, γ_c, P_c, Q_c, K_c, are the values of β, γ, P, Q, and K for the middle cylinder. The total solar radiation force acting on the whole main body of Helios is then

$$F_B = F_{YF} + F_{YC} \quad ,$$

acting in the Sun-spacecraft direction.

V. <u>THE SOLAR RADIATION FORCE ACTING ON OTHER APPENDAGES OF THE HELIOS SPACECRAFT</u>

A very rough calculation of the total solar radiation force acting on all other major components of the spacecraft shows that the maximum contribution to

the force, due to the irradiation of all those components, does not exceed 6.8 per cent of the force exerted on the main body of the spacecraft. Still, in order to perform a complete analysis of the solar pressure effects on Helios, we shall furnish a short synopsis of the solar radiation forces acting on other parts of the spacecraft, shown on Figure 6 and explained in Table 1.

All the components have simple geometric shapes for which the expressions for the solar radiation force have already been derived in References 1-6; they all can be considered as having purely adiabatic surfaces for which $K(r,\theta) = 1$. Particular attention has been given to the derivation of the solar radiation force acting on the despun high-gain antenna, pointed toward the Earth, and its partially shadowed frame. The force acting on the four rapidly rotating booms and instruments has been averaged over one period of rotation (1 sec.). It is very evident that due to the smallness of the forces involved, it has been very beneficial.

COMPONENT NO.	DESCRIPTION
1	Main body
2	High-gain antenna
3	Medium-gain antenna
4	Low-gain antenna
5	Instruments and the dummy counterbalance
6	Instrument carrying booms
7	Booms

TABLE 1

Principal parts of the spacecraft.

and convenient to use approximate expressions which considerably reduce the complexity of the mathematical apparatus applied and ultimately implemented into the computer programme.

VI. COMPUTER PROGRAMME FOR THE CALCULATION OF THE SOLAR RADIATION FORCE.

The solar radiation force is a function of the heliocentric distance of the spacecraft and, up to a lesser extent, of the position of the spacecraft relative to the position of the Earth. Thus, in order to compute a series of values of the solar radiation force over a certain interval of time, we should first compute the positions of the spacecraft in its heliocentric orbit. The relatively small magnitude of the force (the maximum total force is approximately 2.63×10^{-4} N or 26.3 dynes) has led to the conclusion that an unperturbed, elliptical orbit would yield a more than satisfactory accuracy for that purpose. The orbital elements, which served as input data for the calculation of this orbit, were obtained from the personnel of the German Geselschaft fur Welfraumforschung by J. Peyn of the University of Hamburg.

The computer programme, listed in Appendix 1, is entirely self-explanatory via its comment statements, so that additional descriptions and explanations would undoubtedly be superfluous. Although the use of only one space-fixed system of reference axes would be perfectly sufficient (such as the ecliptic system for 1950.0, initially used), the programme also computes the components of the solar radiation force along the axes of the Earth-equatorial reference frame of 1950.0. It also gives the magnitude of the total force acting on the spacecraft. The forces are computed for each day (zero-hour GMT) during one complete orbital period of the spacecraft (approximately 190 days), starting with the day of the insertion into the elliptic orbit, five days after the

launch time; the output is given in Appendix 2. In addition to this, a plotting programme has been used to depict graphically the behaviour of the force components over a period of 400 days. The graphs are shown in Appendix 3.

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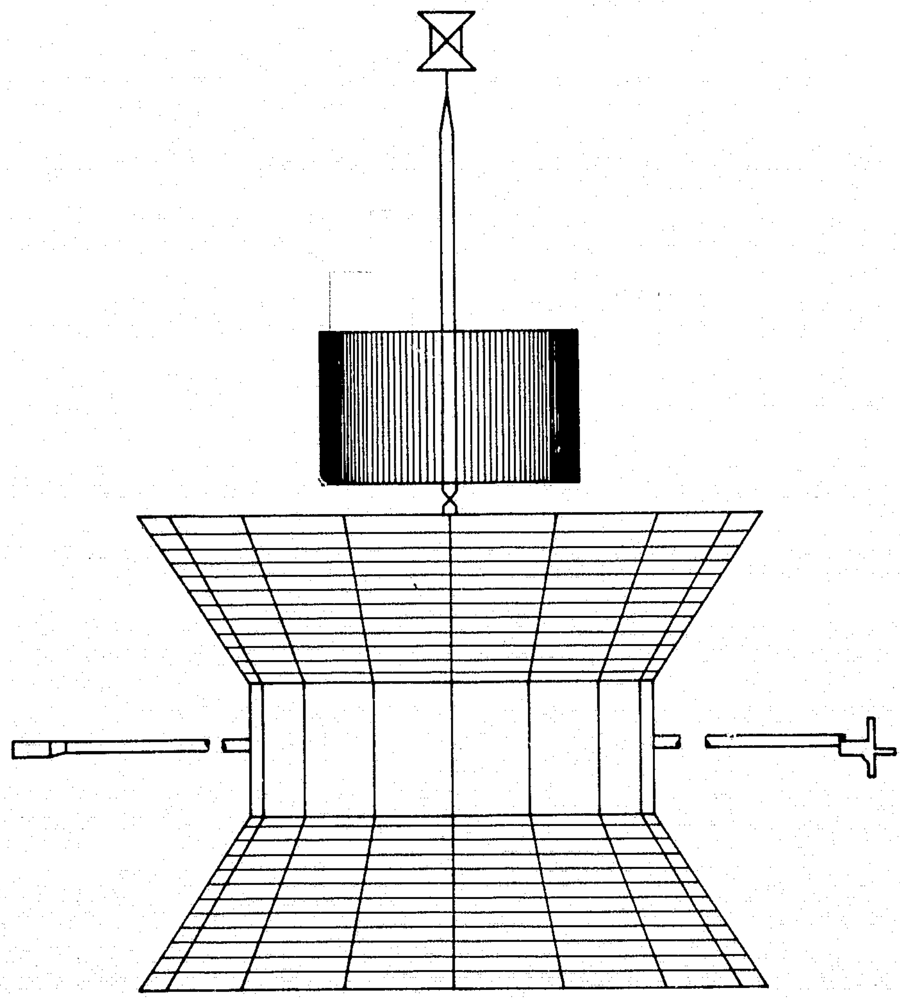


Fig. 1. Side view of the Helios spacecraft

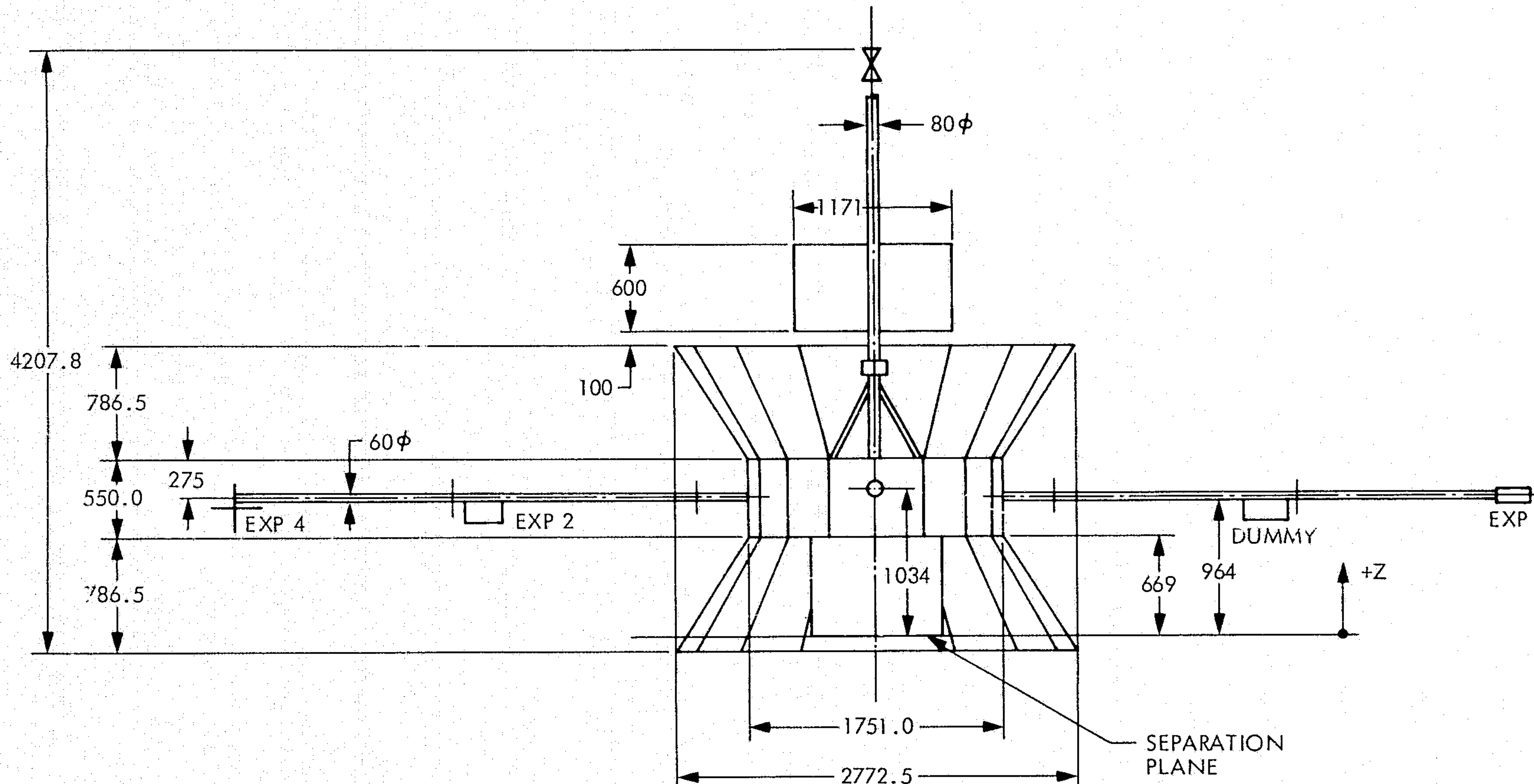


Fig. 2. Side view of the spacecraft

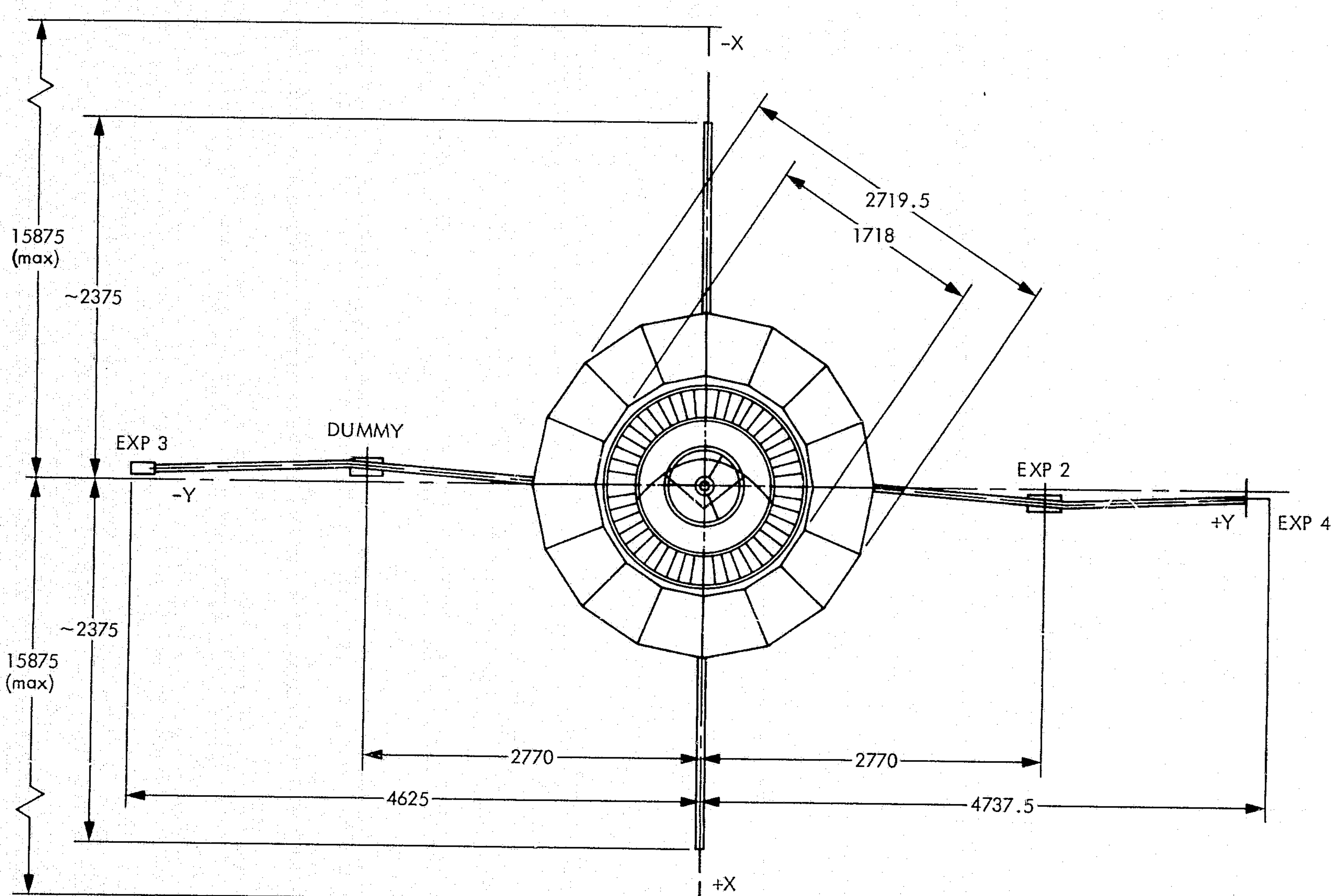
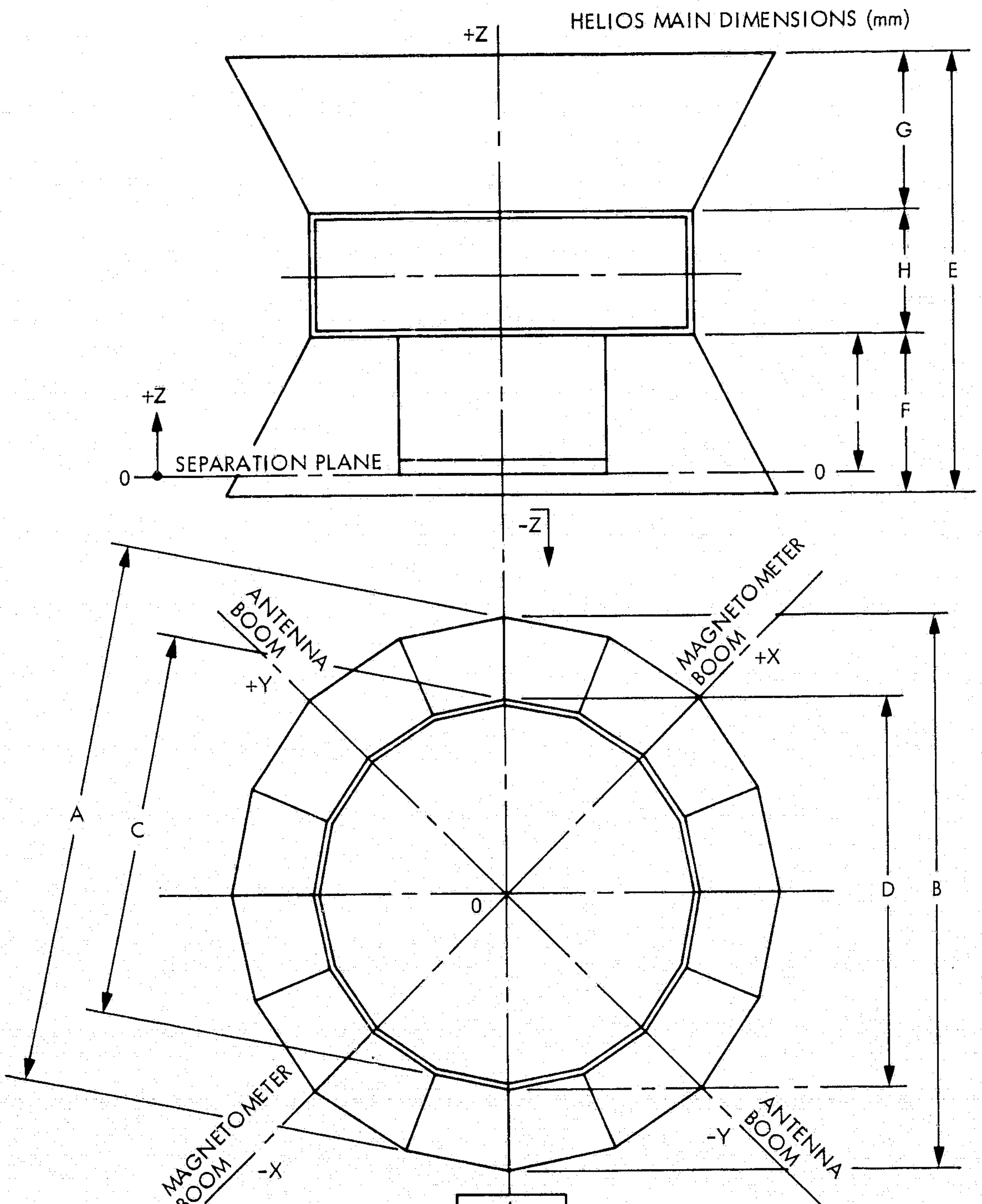


Fig. 3. Top view of the spacecraft



A	B	C	D	E	F	G	H	I
2719.5	2772.5	1717.5	1751.1		786.5	786.5	550	689.0

Fig. 4. Main body (bus) of the spacecraft

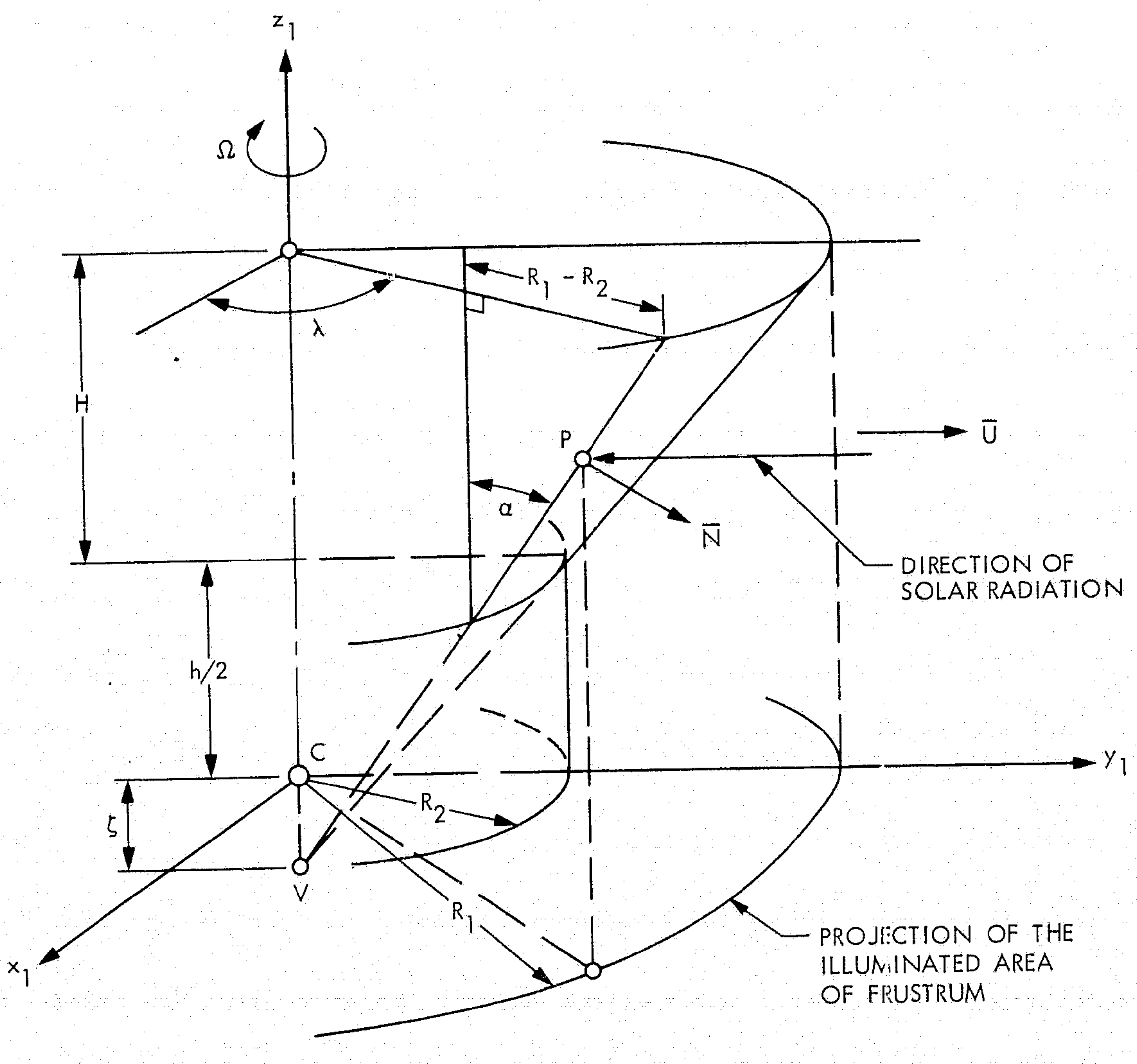


Fig. 5. Geometry of the main body of the spacecraft

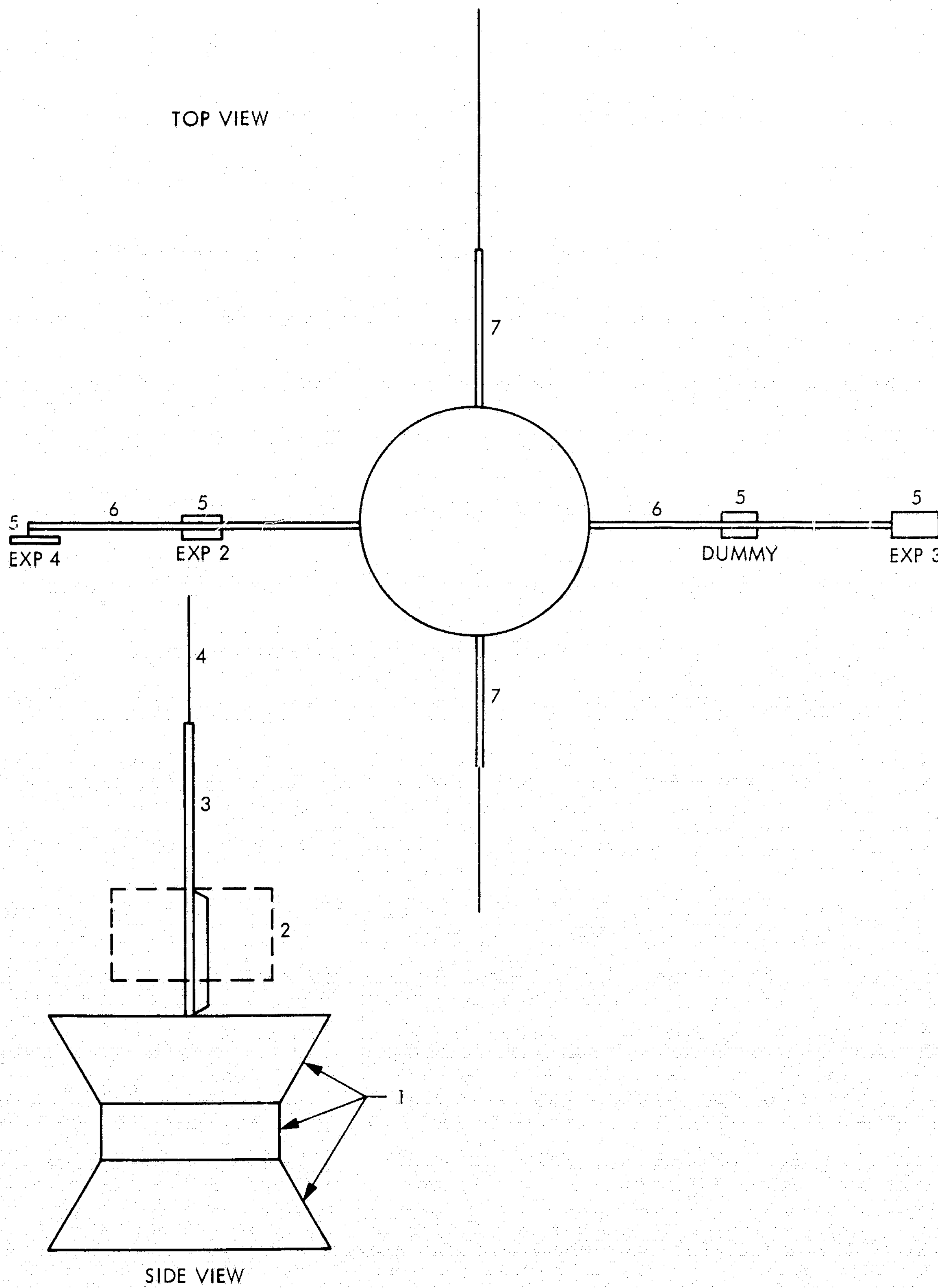


Fig. 6. Principal spacecraft components

APPENDIX 1

The Computer Programme

```
C
C*********************************************************************************************
C
C  NOMENCLATURE
C
C         EPSF   = EMISSIVITY OF THE ILLUMINATED SURFACE
C         EPSB   = EMISSIVITY OF THE BACK SURFACE
C         GAMMA  = REFLECTIVITY COEFFICIENT OF THE ILLUMINATED SURFACE
C         BETA   = SPECULAR REFLECTIVITY PARAMETER OF THE SURFACE
C         SIGMA  = STEFAN-S CONSTANT (5.6697E-08 KG/SEC**3.DEGK**4)
C         SOLAR  = SOLAR CONSTANT (1.353E+03 KG/SEC**3)
C         PSI    = THE SUN-SPACECRAFT-EARTH ANGLE (EPS) IN RADIANS
C         DPSI   = THE SUN-SPACECRAFT-EARTH ANGLE (EPS) IN DEGREES
C         SEP    = SUN-EARTH-SPACECRAFT ANGLE IN RADIANS
C         DSEP   = SUN-EARTH-SPACECRAFT ANGLE IN DEGREES
C         K1     = JAWORSKI-S CONSTANT EPSF/(EPSF+EPSB)
C         ALPHA  = CONE ANGLE OF THE MAIN BODY OF THE SPACECRAFT
C         AX     = THE SEMI-MAJOR AXIS OF THE SPACECRAFT-S ELLIPTIC
C                  ORBIT (KM)
C         AXE    = THE SEMI-MAJOR AXIS OF THE ELLIPTIC ORBIT OF THE EARTH (KM)
C         ECC    = THE ORBITAL ECCENTRICITY OF THE SPACECRAFT
C         ECCE   = ECCENTRICITY OF THE EARTH-S ORBIT
C         EPSLN  = OBLIQUITY OF THE ECLIPTIC
C         INCL   = INCLINATION OF THE ORBITAL PLANE TO THE ECLIPTIC
C                  PLANE OF 1950.0
C         NODE   = NODAL ANGLE OF THE ORBITAL PLANE OF SPACECRAFT
C         OMEGA  = ARGUMENT OF THE PERIAPSIS OF THE SPACECRAFT-S ORBIT
C         EOMEGA = ARGUMENT OF THE EARTH-S PERIAPSIS
C         THETA  = TRUE ANOMALY OF THE SPACECRAFT
C         ETHETA = TRUE ANOMALY OF THE EARTH
C         M      = MEAN ANOMALY OF THE SPACECRAFT
C         ME     = MEAN ANOMALY OF THE EARTH
C         E      = ECCENTRIC ANOMALY OF THE SPACECRAFT
C         EE     = ECCENTRIC ANOMALY OF THE EARTH
C         MSTART = MEAN ANOMALY OF THE SPACECRAFT AT THE TIME OF
C                  INITIALIZATION  T = TSTART
C         MESTRT = MEAN ANOMALY OF THE EARTH AT THE TIME OF INITIALIZATION
C         TSTART = INITIAL TIME
C         GM     = GRAVITATIONAL CONSTANT OF THE SUN
C         MEAN   = MEAN ORBITAL MOTION OF THE SPACECRAFT
C         MEANE  = MEAN ORBITAL MOTION OF THE EARTH
C         PER    = ORBITAL PERIOD OF THE SPACECRAFT
C         PERE   = ORBITAL PERIOD OF THE EARTH
C         N      = NUMBER OF POINTS ON THE TRAJECTORY
C         TSTEP  = TIME STEP (DAYS)
C         RHO    = HELIOCENTRIC POSITION VECTOR OF THE SPACECRAFT IN
C                  ASTRONOMICAL UNITS (AU)
C         RHOE   = HELIOCENTRIC POSITION VECTOR OF THE EARTH IN
C                  ASTRONOMICAL UNITS (AU)
C         UR     = SPACECRAFT-EARTH DISTANCE (KM)
C         R1     = OUTER RADIUS OF THE TRUNCATED CONES (METERS)
C         R2     = RADIUS OF THE MIDDLE CYLINDER (METERS)
C         H      = HEIGHT OF THE TRUNCATED CONES (METERS)
C         HC     = HEIGHT OF THE MIDDLE CYLINDER (METERS)
C         RA     = AVERAGE RADIUS OF THE HIGH-, MEDIUM-, AND LOW-GAIN
C                  ANTENNA BOOMS
C         HA     = TOTAL HEIGHT OF THE THREE ANTENNA BOOMS
C
C  THEORETICAL FORMULATION FOR THE THERMAL RE-RADIATION
C
C         1. EQUATION-
C
C         EPSF*TFRONT**4 + ETA*EPSB*TBACK**4 =
C               (SOLAR/SIGMA)*((AU/R)**2)*(1.-GAMMA)*COS(THETA)
C         (ENERGY BALANCE, GAUSS- THEOREM)
C
```

```
C           2. EQUATION-
C
C           TFRONT = TBACK + (D*SIGMA*EPSB/COND)*TBACK**4
C           (BOUNDARY CONDITIONS, LAPLACE-S EQUATION)
C
C       EPOCH = TSTART = 1974, DECEMBER 10, 00 HRS, 00 MIN, 00 SEC.
C
C   X,Y,Z   ARE ECLIPTIC COORDINATES OF THE SPACECRAFT
C   XQ,YQ,ZQ  ARE EQUATORIAL COORDINATES OF THE SPACECRAFT
C   XE,YE,ZE=0 ARE ECLIPTIC COORDINATES OF THE EARTH
C
C   REFERENCES-
C
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C       4. R.M.GEORGEVIC, PROGRAM -MVMSOL-, MAY, 1974
C
C*************************************************************************************
C
C   SPECIFICATIONS-
C
      REAL INCL,NODE
      REAL IXX,IYY,IZZ
      REAL MSTART,MZERO,MESTRT,MEAN,MEANE,MASS
      REAL I1,I2,K1
      REAL M(400),ME(400),NORM(28)
      DIMENSION THETA(400),ETHETA(400),X(400),Y(400),R(400),Z(400),
     *  XE(400),YE(400),RE(400)
      DIMENSION UX(400),UY(400),UZ(400)
      DIMENSION PSI(400),DPSI(400),RHO(400),RHOE(400),TIME(400)
      DIMENSION E(400),EE(400),DTHETA(400),DETHTA(400)
      DIMENSION DM(400),DME(400),DE(400),DEE(400)
      DIMENSION UR(400),FBX(400),FBY(400),FBZ(400),BACC(400),
     *   BFORCE(400)
      DIMENSION XQ(400),YQ(400),ZQ(400),SEP(400),DSEP(400),
     *  BFX(400),BFY(400),BFZ(400)
      DIMENSION FTX(400),FTY(400),FTZ(400)
      DIMENSION FTMAG(400),TACC(400)
      DIMENSION TFY1(400),FAV(400),FLAT(400)
      DIMENSION AREA(28)
      DIMENSION SDIST(400)
      DIMENSION FLAG(28)
      DATA PI/3.141592654/,DAY/86400./,SPEED/2.997925E+08/
      DATA I1/1.382638/,I2/1.248598/
      DATA R1/1.373/,R2/0.86713/,H/0.7865/,HC/0.550/
      DATA DT/128.2152777778/
C
      NAMELIST/INPUT/EPSF,EPSB,GAMAN,SIGMA,SOLAR,BETA,COND,ECCE,TSTART,
     1   TSTEP,AXE,EOMEGA,EPSLN,GM,MASS,AU,MZERO,N,DEPTH,TLNCH,IXX,IYY,
     2   IZZ,INCL,NODE,AX,OMEGA,ECC,MESTRT,NORM,AREA,GAMSA,GAMCC,RA,HA,
     3  ABETA
C
      RAD = 180.0/PI
 7000 READ(5,INPUT)
      WRITE(6,3000)
      WRITE(6,INPUT)
      WRITE(6,1000)
 3000 FORMAT(1H1,4X////)
 1000 FORMAT(1H1,1X,/)
      DO 888 J=1,28
      AREA(J) = AREA(J)/10000.
      NORM(J) = NORM(J)/RAD
  888 CONTINUE
      ALPHA = ATAN((R1-R2)/H)
      MEAN = SQRT(GM/AX**3)
      MEANE = SQRT(GM/AXE**3)
```

```
      DMEAN = MEAN*DAY*RAD
      DMEANE = MEANE*DAY*RAD
      IF(MESTRT.GT.360.0)MESTRT=MESTRT-360.0
      PER = 2.0*PI/(MEAN*DAY)
      PERE = 2.0*PI/(MEANE*DAY)
      ETA = SQRT((1.0+ECC)/(1.0-ECC))
      ETAL = SQRT((1.0+ECCE)/(1.0-ECCE))
      IF(OMEGA.LT.0.0)OMEGA = OMEGA + 360.0
      MSTART = MZERO - DMEAN*DT
      IF(MSTART.LT.0.)MSTART=MSTART+360.
 2003 WRITE(6,2)
      WRITE(6,3)AX,ECC,OMEGA,MSTART,DMEAN,PER,INCL,NODE
      WRITE(6,4)
      WRITE(6,31)AXE,ECCE,EOMEGA,MESTRT,DMEANE,PERE
    2 FORMAT(36X,-HELIOCENTRIC EQUATORIAL ORBITAL PARAMETERS OF THE -,
     * -SPACECRAFT-//)
    3 FORMAT(38X,-AX =-,E16.8,1X,-KM-/,37X,-ECC =-,F16.11/,35X,-OMEGA =-
     1  ,F16.11,1X,-DEG-/,34X,-MSTART =-,F16.11,1X,-DEG-/,36X,-MEAN =-,
     2   F16.11,1X,-DEG/DAY-/,34X,-PERIOD =-,F16.11,1X,-DAYS-/,36X,
     3  -INCL =-,F16.11,1X,-DEG-/,36X,-NODE =-,F16.11,1X,-DEG-///)
    4 FORMAT( /36X,-HELIOCENTRIC ECLIPTIC ORBITAL PARAMETERS OF THE -,
     1    -EARTH-//)
   31 FORMAT(38X,-AX =-,E16.8,1X,-KM-/,37X,-ECC =-,F16.11/,35X,-OMEGA =-
     1  ,F16.11,1X,-DEG-/,34X,-MSTART =-,F16.11,1X,-DEG-/,36X,-MEAN =-,
     2   F16.11,1X,-DEG/DAY-/,34X,-PERIOD =-,F16.11,1X,-DAYS-////)
      OMEGA = OMEGA/RAD
      EOMEGA = EOMEGA/RAD
      EPSLN = EPSLN/RAD
      SE = SIN(EPSLN)
      CE = COS(EPSLN)
      MSTART = MSTART/RAD
      MESTRT = MESTRT/RAD
      INCL = INCL/RAD
      NODE = NODE/RAD
      CI = COS(INCL)
      SI = SIN(INCL)
      CN = COS(NODE)
      SN = SIN(NODE)
      CO = COS(OMEGA)
      SO = SIN(OMEGA)
C
C  CONVERSION OF EQUATORIAL ORBITAL PARAMETERS FOR 1950.0 INTO ECLIPTIC
C  PARAMETERS FOR 1950.
C
      SC = CE*SI - SE*CI*CN
      SS = SE*SN
      SNI = SQRT(SS**2+SC**2)
      CSI = CI*CE + SI*SE*CN
      INCL = ATAN2(SNI,CSI)
      DELOM = ATAN(SS/SC)
      OMEGA = OMEGA-DELOM
      SNODE =  SI*SIN(DELOM)/SE
      NODE = ASIN(SNODE)
      DINCL = INCL*RAD
      DOMEGA = OMEGA*RAD
      DNODE = NODE*RAD
      WRITE(6,97)
      WRITE(6,98)DOMEGA,DINCL,DNODE
   97 FORMAT(36X,-ECLIPTIC ANGULAR ORBITAL PARAMETERS OF THE SPACEC-,
     *  -RAFT-//)
   98 FORMAT(35X,-OMEGA =-,F16.11,1X,-DEG-/,36X,-INCL =-,F16.11,1X,
     *  -DEG-/,36X,-NODE =-,F16.11,1X,-DEG-///)
C
C  COMPUTATION OF UNPERTURBED POSITIONS OF THE SPACECRAFT AND THE EARTH
C
      SI = SIN(INCL)
      CI = COS(INCL)
```

```
      SN = SIN(NODE)
      CN = COS(NODE)
      SO = SIN(OMEGA)
      CO = COS(OMEGA)
      PX = CN*CO - SN*SO*CI
      PY = SN*CO + CN*SO*CI
      PZ = SO*SI
      QX = -CN*SO - SN*CO*CI
      QY = -SN*SO + CN*CO*CI
      QZ = CO*SI
      RX = SN*SI
      RY = -CN*SI
      RZ = CI
      TEST1 = PX**2 + PY**2 + PZ**2 -1.
      TEST2 = QX**2 + QY**2 + QZ**2 -1.
      TEST3 = RX**2 + RY**2 + RZ**2 -1.
      TEST4 = PX**2 + QX**2 + RX**2 -1.
      TEST5 = PY**2 + QY**2 + RY**2 -1.
      TEST6 = PZ**2 + QZ**2 + RZ**2 -1.
      TEST7 = PX*QX + PY*QY + PZ*QZ
      TEST8 = PX*RX + PY*RY + PZ*RZ
      TEST9 = QX*RX + QY*RY + QZ*RZ
      TEST10 = PX*PY + QX*QY + RX*RY
      TEST11 = PX*PZ + QX*QZ + RX*RZ
      TEST12 = PY*PZ + QY*QZ + RY*RZ
      WRITE(6,8)
      WRITE(6,909)PX,PY,PZ,QX,QY,QZ,RX,RY,RZ
      WRITE(6,11)
      WRITE(6,8012)TEST1,TEST2,TEST3,TEST4,TEST5,TEST6,TEST7,TEST8,
     *   TEST9,TEST10,TEST11,TEST12
    8 FORMAT( /36X,-VECTORS P,Q,R OF THE SPACECRAFT-//,36X,-ECLIPTIC-/)
  909 FORMAT(10X,-PX =-,F10.6,10X,-PY =-,F10.6,10X,-PZ =-,F10.6/,
     1   10X,-QX =-,F10.6,10X,-QY =-,F10.6,10X,-QZ =-,F10.6/,10X,
     2   -RX =-,F10.6,10X,-RY =-,F10.6,10X,-RZ =-,F10.6//)
   11 FORMAT(//36X,-ORTHOGONALITY TESTS-/)
 8012 FORMAT(/(4F15.6))
      NP = N/50 + 1
      DO 16 NPTS = 1,N
      M(NPTS) = MSTART + (NPTS-1)*MEAN*TSTEP
      ME(NPTS) = MESTRT + (NPTS-1)*MEANE*TSTEP
      E(NPTS) = ANOM(ECC,M(NPTS))
      EE(NPTS) = ANOM(ECCE,ME(NPTS))
      R(NPTS) = AX*(1.0-ECC*COS(E(NPTS)))
      RE(NPTS) = AXE*(1.0-ECCE*COS(EE(NPTS)))
      RHO(NPTS) = R(NPTS)/AU
      RHOE(NPTS) = RE(NPTS)/AU
      THETA(NPTS) = 2.0*ATAN(ETA*TAN(E(NPTS)/2.0))
      ETHETA(NPTS) = 2.0*ATAN(ETAE*TAN(EE(NPTS)/2.0))
      IF(E(NPTS).GE.2.0*PI)E(NPTS)=E(NPTS)-2.0*PI
      IF(EE(NPTS).GE.2.0*PI)EE(NPTS)=EE(NPTS)-2.0*PI
      IF(M(NPTS).GE.2.0*PI)M(NPTS)=M(NPTS)-2.0*PI
      IF(ME(NPTS).GE.2.0*PI)ME(NPTS)=ME(NPTS)-2.0*PI
      XORB        = R(NPTS)*COS(THETA(NPTS))
      YORB        = R(NPTS)*SIN(THETA(NPTS))
      X(NPTS) = PX*XORB + QX*YORB
      Y(NPTS) = PY*XORB + QY*YORB
      Z(NPTS) = PZ*XORB + QZ*YORB
      XG(NPTS) = X(NPTS)
      YG(NPTS) = Y(NPTS)*CE - Z(NPTS)*SE
      ZG(NPTS) = Y(NPTS)*SE + Z(NPTS)*CE
         XE(NPTS) = RE(NPTS)*COS(ETHETA(NPTS) + EOMEGA)
         YE(NPTS) = RE(NPTS)*SIN(ETHETA(NPTS) + EOMEGA)
      TIME(NPTS) = TSTART + ((NPTS-1)*TSTEP)/DAY - TLNCH
            UX(NPTS) = X(NPTS)-XE(NPTS)
            UY(NPTS) = Y(NPTS)-YE(NPTS)
            UZ(NPTS)   Z(NPTS)
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      URSQ = UX(NPTS)**2 + UY(NPTS)**2 + UZ(NPTS)**2
      UR(NPTS) = SQRT(URSQ)
C
C   CX,CY,CZ ARE COMPONENTS OF THE CROSS-PRODUCT (VECTOR-PRODUCT) (R X RE)
C
C   SIN(PSI) AND SIN(SEP) ARE DETERMINED FROM CROSS-PRODUCTS  (RE X R) AND
C   (R X RE), RESPECTIVELY.
C   COS(PSI) AND COS(SEP) ARE DETERMINED FROM DOT-PRODUCTS (SCALAR PRODUCTS
C   (UR.R) AND (UR.RE), RESPECTIVELY.
C
C   THE SIGN OF SIN(PSI) IS DETERMINED IN SUCH A MANNER THAT SIN(PSI) IS
C   POSITIVE IF CZ IS NEGATIVE. THE ANGLE PSI IS MEASURED FROM R TO UR IN
C   THE POSITIVE DIRECTION
C
           CX = -Z(NPTS)*YE(NPTS)
           CY = Z(NPTS)*XE(NPTS)
           CZ = X(NPTS)*YE(NPTS) - Y(NPTS)*XE(NPTS)
      CSQ = CX**2 + CY**2 + CZ**2
      DOT = UX(NPTS)*X(NPTS) + UY(NPTS)*Y(NPTS) + UZ(NPTS)*Z(NPTS)
      SPSI = SQRT(CSQ)/(UR(NPTS)*R(NPTS))
      IF(CZ.LT.0.)SPSI=-SPSI
      CPSI = DOT/(UR(NPTS)*R(NPTS))
      PSI(NPTS) = ATAN2(SPSI,CPSI)
      DPSI(NPTS) = PSI(NPTS)*RAD
      IF(DPSI(NPTS).LT.0  DPSI(NPTS)=DPSI(NPTS)+360.
      PDOT = UX(NPTS)*XE(NPTS) + UY(NPTS)*YE(NPTS)
      SNSEP = SPSI*R(NPTS)/RE(NPTS)
      COSEP = -PDOT/(UR(NPTS)*RE(NPTS))
      SEP(NPTS) = ATAN2(SNSEP,COSEP)
      DSEP(NPTS) = SEP(NPTS)*RAD
C
C   CALCULATION OF THE SHORTEST DISTANCE FROM THE SUN TO THE GEOCENTRIC
C   LIGHT RAY PATH
C
      DIST = R(NPTS)*SIN(PSI(NPTS))
      SDIST(NPTS) = ABS(DIST)
      DO 18 LIST=1,NP
      LL = 50*(LIST-1)+1
      IF(NPTS.EQ.LL)WRITE(6,180)
  180 FORMAT(1H1,1X,
     1          -TIME-,6X,-X(KM)-,9X,-Y(KM)-,9X,-Z(KM)-,9X,-RHO(AU)-,
     2  5X,-XE(KM)-,8X,-YE(KM)-,10X,          -RHOE-,8X,-PSI-/,
     3   1X,-(DAYS)-, 69X,-(AU)-,7X,-(DEG)-/)
   18 CONTINUE
      WRITE(6,19)TIME(NPTS),
     1           X(NPTS),Y(NPTS),Z(NPTS),RHO(NPTS),XE(NPTS),YE(NPTS),
     2            RHOE(NPTS),DPSI(NPTS)
   19 FORMAT(1X,F6.2,3E14.6,F12.6,2E14.6,F12.6,F11.2)
   16 CONTINUE
      DO 33 NPTS=1,N
      DTHETA(NPTS) = THETA(NPTS)*RAD
      DETHTA(NPTS) = ETHETA(NPTS)*RAD
      IF(DTHETA(NPTS).LT.0.0)DTHETA(NPTS)=DTHETA(NPTS)+360.0
      IF(DETHTA(NPTS).LT.0.0)DETHTA(NPTS)=DETHTA(NPTS)+360.0
      DM(NPTS) = M(NPTS)*RAD
      DME(NPTS) = ME(NPTS)*RAD
      DE(NPTS) = E(NPTS)*RAD
      DEE(NPTS) = EE(NPTS)*RAD
      IF(DM(NPTS).LT.0.0)DM(NPTS)=DM(NPTS)+360.
      IF(DME(NPTS).LT.0.0)DME(NPTS)=DME(NPTS)+360.0
      IF(DE(NPTS).LT.0.0)DE(NPTS)=DE(NPTS)+360.
      IF(DEE(NPTS).LT.0.0)DEE(NPTS)=DEE(NPTS)+360.0
      IF(DE(NPTS).GE.360.0)DE(NPTS)=DE(NPTS)-360.0
      IF(DEE(NPTS).GE.360.0)DEE(NPTS)=DEE(NPTS)-360.0
      IF(DM(NPTS).GE.360.0)DM(NPTS)=DM(NPTS)-360.0
      IF(DME(NPTS).GE.360.0)DME(NPTS)=DME(NPTS)-360.0
      DO 119 LIST=1,NP
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```
      LL = 50*(LIST-1)+1
      IF(NPTS.EQ.LL)WRITE(6,182)
  182 FORMAT(1H1,29X,-TIME-,5X,-THETA-,6X,-E-,8X,-M-,5X,-THETAE-,5X,
     1   -EE-,7X,-ME-,7X,-SDIST-/,29X,-(DAYS)-,6(4X,-(DEG)-),6X,-(KM)-/)
  119 CONTINUE
      WRITE(6,190)TIME(NPTS),DTHETA(NPTS),DE(NPTS),DM(NPTS),
     1   DETHTA(NPTS),DEE(NPTS),DME(NPTS),SDIST(NPTS)
  190 FORMAT(29X,F6.2,6F9.2,E14.6)
   33 CONTINUE
C
C  AUXILIARY PARAMETERS FOR THE CALCULATION OF THERMAL RE-RADIATION EFFECTS
C
      ELES = -1000000.0*SOLAR/SPEED
      EPS = EPSF+EPSB
      K1  = EPSF/EPS
C
C  -SA- MEANS SOLAR ARRAY (TRUNCATED CONES)
C  -CC- MEANS CENTRAL COMPARTMENT (CYLINDER)
C
      TEMSA = SOLAR*(1.-GAMSA)/(SIGMA*EPS)
      TEMCC = SOLAR*(1.-GAMCC)/(SIGMA*EPS)
      TSTSA=TEMSA**0.25
      TSTCC=TEMCC**0.25
      C = SIGMA*DEPTH*EPSB/COND
      ASA=C*TSTSA**3.
      ACC = C*TSTCC**3
      BSA=3.*ASA*K1
      BCC = 3.*ACC*K1
      PSA = 4.*EPSF*EPSB*ASA/EPSF**2
      PCC = 4.*EPSF*EPSB*ACC/EPSF**2
      QNUM = -2.0*EPSF*EPSB*(11.0*EPSF-3.0*EPSB)
      QSA = QNUM*(ASA**2)/EPS**3
      QCC = QNUM*(ACC**2)/EPS**3
C
C  THE BODY OF THE HELIOS SPACECRAFT CONSISTS OF-
C
C  1. MAIN BODY OF THE SPACECRAFT - TWO TRUNCATED CONES AND THE CYLINDER IN
C     THE MIDDLE. ONLY THIS PART CONTAINS THE THERMAL RE-RADIATION EFFECTS.
C  2. THREE ANTENNA BOOMS- HIGH-, MEDIUM-, AND LOW-GAIN ANTENNA BOOMS.
C  3. FOUR ROTATING SPACECRAFT BOOMS. THE SOLAR FORCE WILL BE CALCULATED
C     BY AVERAGING OVER ONE PERIOD OF ROTATION.
C  4. ANTENNA WIRES.
C  5. FLAT PARTS OF THE FRAME OF THE HIGH-GAIN ANTENNA REFLECTOR.
C  6. PARABOLICALLY SHAPED FRAME OF THE HIGH-GAIN ANTENNA.
C
C  CALCULATION OF THE SOLAR RADIATION FORCE ACTING ON THE MAIN BODY OF THE
C  HELIOS SPACECRAFT
C
C  1. CALCULATION OF THE SOLAR RADIATION FORCE ON TWO TRUNCATED CONES
C
      CT1 = 2.*ELES*H*(R1+R2)/3.
      CA = COS(ALPHA)
      T1 = 4.*BETA*GAMSA*CA**2
      T2 = .5*PI*CA*(GAMSA*(1.-BETA) + (1.-GAMSA)*K1)
      T3 = 3.*(1.-BETA*GAMSA)
      T4 = (1.-GAMSA)*PSA*I1*CA**1.75
      T5 = (1.-GAMSA)*QSA*I2*CA**2.5
      TRM1 = CT1*(T1 + T2 + T3)
      TRM2 = CT1*T4
      TRM3 = CT1*T5
C
C  2. SOLAR RADIATION FORCE ON THE MIDDLE CYLINDER
C
      CT2 = 2.*ELES*R2*HC/3.
      T6 = 4.*BETA*GAMCC + 3.*(1.-BETA*GAMCC)
      T7 = .5*PI*(GAMCC*(1.-BETA) + (1.-GAMCC)*K1)
      T8 = (1.-GAMCC)*PCC*I1
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      T9 = (1.-GAMCC)*QCC*12
      TRM4 = CT2*(T6 + T7)
      TRM5 = CT2*T8
      TRM6 = CT2*T9
C
C   TOTAL HELIOS BODY RADIATION FORCE = SOLAR RADIATION FORCE ON THE TWO
C   TRUNCATED CONES PLUS THE FORCE ON THE MIDDLE CYLINDER
C
      TERM1 = TRM1 + TRM4
      TERM2 = TRM2 + TRM5
      TERM3 = TRM3 + TRM6
C
C   CALCULATION OF THE SOLAR RADIATION FORCE ON THE ANTENNA BOOMS
C
      CTA = 2.*ELES*RA*HA/3.
      T10 = 4.*ABETA*GAMCC + 3.*(1.-ABETA*GAMCC)
      T11 = .5*PI*(GAMCC*(1.-ABETA)+(1.-GAMCC)*K1)
      TRM7 = CTA*(T10+T11)
C
C   CALCULATION OF THE SOLAR RADIATION FORCE ACTING ON THE FOUR ROTATING
C   SPACECRAFT BOOMS, AVERAGED OVER ONE PERIOD
C
      AB1 = .043
      AB2 = .0254
      AB3 = .00335
      ABH1 = 3.768
      ABH2 = 1.58
      ABH3 = 14.0
      BG = .60
      ABCF = ELES*PI*(1.-BG)*(2.*AB1*ABH1 + 2.*AB2*ABH2 + AB3*ABH3)/6.
C
C   CALCULATION OF THE SOLAR RADIATION FORCE ACTING ON THE ANTENNA REFLECTOR
C   WIRES
C
      WCF = -.2
C
      DALPHA = ALPHA*RAD
      ELAM = ELES/1000000.0
      ATR2 = TERM1/1000000.
      ATR35 = TERM2/1000000.
      ATR5 = TERM3/1000000.
      WRITE(6,100)DALPHA,ELES,ELAM,K1,TSTSA,TSTCC,PSA,PCC,QSA,QCC,
     * ATR2,ATR35,ATR5
      WRITE(6,6)
  100 FORMAT(1H1,////,11X,-PHYSICAL CONSTANTS FOR CALCULATION OF THE -
     1   -SOLAR RADIATION FORCE ON THE MAIN-/,12X,-BODY OF THE HELIOS -
     2   -SPACECRAFT-,
     3            /////,24X,-ALPHA =-,F12.6,1X,-DEG-/,25X,-ELES =-,
     4   E15.6/,23X,-LAMBDA =-,E15.6/,
     5   27X,-K1 =-,F12.6/,24X,-TSTAR =-,2F9.3/,28X,-P =-,2E14.5/,28X,
     6   -Q =-,2E14.5//,26X,-TR2 =-,E14.5/,25X,-TR35 =-,E14.5/,26X,
     7   -TR5 =-,E14.5//)
    6 FORMAT(1H1,25(/),25X,
     1                 -COMPONENTS OF THE SOLAR RADIATION FORCE ACTING ON -
     2  -THE MAIN BODY OF THE-/,25X,-HELIOS SPACECRAFT-,
     3   - IN THE SPACE-FIXED,BODY-CENTERED ECLIPTIC REFERENCE FRAME.-//
     4  ,25X,-(FORCE -,
     5   -GIVEN IN E-06 NEWTONS, ACCELERATION IN E-11 KM/SEC**2)-//)
      AVTOT = 0.0
      DO 1 NPTS=1,N
      RM1 = 1.0/RHO(NPTS)
C
C   TOTAL FORCE IN THE SUN-SPACECRAFT DIRECTION
C
C   1.- FORCE ON THE MAIN BODY OF THE SPACECRAFT
      FY1 = TERM1*RM1**2 + TERM2*RM1**3.5 + TERM3*RM1**5
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C   2.- FORCE ON THE ANTENNA BOOMS
      FYA = TRM7*RM1**2
C   3.- FORCE ON THE FOUR ROTATING BOOMS OF THE SPACECRAFT (AVERAGED OVER
C       ONE PERIOD)
      FYAB = ABCF*RM1**2
C   4.- FORCE ON THE WIRES OF THE ANTENNA REFLECTOR
      FYAW = WCF*RM1**2
C
C   TOTAL FORCE (SUM OF FORCES 1. THROUGH 4.) IN THE SUN-SPACECRAFT DIRECTION
C
      FYTOT = FY1 + FYA + FYAB + FYAW
C
C   FBX, FBY, FBZ ARE COMPONENTS OF THE SOLAR RADIATION FORCE ACTING ON THE
C   MAIN BODY OF THE HELIOS SPACECRAFT, ALONG THE AXES OF THE SPACE-FIXED,
C   BODY-CENTERED ECLIPTIC REFERENCE FRAME
C
      FBX(NPTS) =        FY1*X(NPTS)/R(NPTS)
      FBY(NPTS) =        FY1*Y(NPTS)/R(NPTS)
      FBZ(NPTS) =        FY1*Z(NPTS)/R(NPTS)
C
C   BFX, BFY, AND BFZ ARE COMPONENTS OF THE SOLAR RADIATION FORCE ACTING
C   ON THE MAIN BODY OF THE SPACECRAFT IN THE INERTIAL EQUATORIAL, BODY-CENTERED
C   REFERENCE FRAME
C
      BFX(NPTS) = FBX(NPTS)
      BFY(NPTS) = FBY(NPTS)*CE - FBZ(NPTS)*SE
      BFZ(NPTS) = FBY(NPTS)*SE + FBZ(NPTS)*CE
C
      BFORCE(NPTS) = ABS(FY1)
      BACC(NPTS) = 100.0*BFORCE(NPTS)/MASS
      DO 5 LIST=1,NP
      LL = 50*(LIST-1) +1
      IF(NPTS.EQ.LL)WRITE(6,7)
    7 FORMAT(1H1,30X,-TIME-, 9X,-FBX-,11X,-FBY-,11X,-FBZ-,10X,-FORCE-
     *  10X,-ACC-,11X,-RHO-/)
    5 CONTINUE
      WRITE(6,9)TIME(NPTS),FBX(NPTS),FBY(NPTS),FBZ(NPTS),BFORCE(NPTS),
     *    BACC(NPTS),RHO(NPTS)
    9 FORMAT(29X,F6.2,6F14.5)
C
C   CALCULATION OF THE COMPONENTS OF THE SOLAR RADIATION FORCE ACTING ON THE
C   FRAME OF THE ANTENNA IN THE ECLIPTIC, SPACE-FIXED, BODY-CENTERED REFERENCE
C   FRAME
C
      XTOT = 0.
      YTOT = 0.
      ZTOT = 0.
      DO 12 J=1,28
      FLAG(J) = 0.
      U = OMEGA + THETA(NPTS)
      UPAP = U + NORM(J) + PSI(NPTS)
      ENX = -COS(UPAP)
      ENY = SIN(UPAP)
      PPA = PSI(NPTS) + NORM(J)
      CPP = COS(PPA)
      CRF = ELES*RM1**2*AREA(J)*CPP
      CFA = 2.*BETA*GAMAN*CPP + 2.*(1.-BETA*GAMAN)/3.
      IF(DPSI(NPTS).GT.0..AND.DPSI(NPTS).LT.180.)FLAG(1)=1.
      IF(DPSI(NPTS).GT.0..AND.DPSI(NPTS).LT.180.)FLAG(2)=1.
      IF(DPSI(NPTS).GT.45..AND.DPSI(NPTS).LT.225.)FLAG(3)=1.
      IF(DPSI(NPTS).GT.45..AND.DPSI(NPTS).LT.225.)FLAG(4)=1.
      IF(DPSI(NPTS).GT.45..AND.DPSI(NPTS).LT.225.)FLAG(5)=1.
      IF(DPSI(NPTS).GT.90..AND.DPSI(NPTS).LT.270.)FLAG(6)=1.
      IF(DPSI(NPTS).GT.90..AND.DPSI(NPTS).LT.225.)FLAG(7)=1.
      IF(DPSI(NPTS).GT.90..AND.DPSI(NPTS).LT.180.)FLAG(8)=1.
      IF(DPSI(NPTS).GT.90..AND.DPSI(NPTS).LT.180.)FLAG(9)=1.
      IF(DPSI(NPTS).GT.90..AND.DPSI(NPTS).LT.270.)FLAG(10)=1.
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      IF(DPSI(NPTS).GT.135..AND.DPSI(NPTS).LT.315.)FLAG(11)=1.
      IF(DPSI(NPTS).GT.135..AND.DPSI(NPTS).LT.315.)FLAG(12)=1.
      IF(DPSI(NPTS).GT.135..AND.DPSI(NPTS).LT.315.)FLAG(13)=1.
      IF(DPSI(NPTS).GT.135..AND.DPSI(NPTS).LT.270.)FLAG(14)=1.
      IF(DPSI(NPTS).GT.180..AND.DPSI(NPTS).LT.270.)FLAG(15)=1.
      IF(DPSI(NPTS).GT.180..AND.DPSI(NPTS).LT.270.)FLAG(16)=1.
      IF(DPSI(NPTS).GT.180..AND.DPSI(NPTS).LT.360.)FLAG(17)=1.
      IF(DPSI(NPTS).GT.180..AND.DPSI(NPTS).LT.360.)FLAG(18)=1.
      IF(DPSI(NPTS).GT.0..AND.DPSI(NPTS) .LT.45..OR.DPSI(NPTS).GT.225.
     1.AND.DPSI(NPTS).LT.360.)FLAG(19)=1.
      IF(DPSI(NPTS).GT.0..AND.DPSI(NPTS) .LT.45..OR.DPSI(NPTS).GT.225.
     1.AND.DPSI(NPTS).LT.360.)FLAG(20)=1.
      IF(DPSI(NPTS).GT.0..AND.DPSI(NPTS) .LT.45..OR.DPSI(NPTS).GT.225.
     1.AND.DPSI(NPTS).LT.360.)FLAG(21)=1.
      IF(DPSI(NPTS).GT.0..AND.DPSI(NPTS) .LT.54..OR.DPSI(NPTS).GT.233.
     1.AND.DPSI(NPTS).LT.360.)FLAG(22)=1.
      IF(DPSI(NPTS).GT.0..AND.DPSI(NPTS) .LT.90..OR.DPSI(NPTS).GT.270.
     1.AND.DPSI(NPTS).LT.360.)FLAG(23)=1.
      IF(DPSI(NPTS).GT.0..AND.DPSI(NPTS) .LT.90..OR.DPSI(NPTS).GT.270.
     1.AND.DPSI(NPTS).LT.360.)FLAG(24)=1.
      IF(DPSI(NPTS).GT.0..AND.DPSI(NPTS) .LT.126..OR.DPSI(NPTS).GT.306.
     1.AND.DPSI(NPTS).LT.360.)FLAG(25)=1.
      IF(DPSI(NPTS).GT.0..AND.DPSI(NPTS) .LT.135..OR.DPSI(NPTS).GT.315.
     1.AND.DPSI(NPTS).LT.360.)FLAG(26)=1.
      IF(DPSI(NPTS).GT.0..AND.DPSI(NPTS) .LT.135..OR.DPSI(NPTS).GT.315.
     1.AND.DPSI(NPTS).LT.360.)FLAG(27)=1.
      IF(DPSI(NPTS).GT.0..AND.DPSI(NPTS) .LT.135..OR.DPSI(NPTS).GT.315.
     1.AND.DPSI(NPTS).LT.360.)FLAG(28)=1.
      AFX = CRF*(CFA*ENX - (1.-BETA*GAMAN)*X(NPTS)/R(NPTS))*FLAG(J)
      AFY = CRF*(CFA*ENY - (1.-BETA*GAMAN)*Y(NPTS)/R(NPTS))*FLAG(J)
      AFZ = -CRF*(1.-BETA*GAMAN)*Z(NPTS)*FLAG(J)/R(NPTS)
      XTOT = XTOT + AFX
      YTOT = YTOT + AFY
      ZTOT = ZTOT + AFZ
   12 CONTINUE
      AFTX = XTOT
      AFTY = YTOT
      AFTZ = ZTOT
C
C  CALCULATION OF THE SOLAR RADIATION FORCE ACTING ON THE PARABOLIC ANTENNA
C  FRAME
C
      CF = .3*RM1**2/SIN(PSI(NPTS))
      XPT = UX(NPTS)*COS(PSI(NPTS))/UR(NPTS)-X(NPTS)/R(NPTS)
      YPT = UY(NPTS)*COS(PSI(NPTS))/UR(NPTS)-Y(NPTS)/R(NPTS)
      PFX = -CF*XPT*.25*SIN(PSI(NPTS))
      PFY = -CF*YPT*COS(PSI(NPTS))
C
C  TFX, TFY, TFZ, ARE THE COMPONENTS OF THE RESULTANT SOLAR RADIATION FORCE
C  ACTING ON THE WHOLE BODY OF THE HELIOS SPACECRAFT, ALONG THE AXES OF THE
C  ECLIPTIC, SPACE-FIXED, BODY-CENTERED REFERENCE FRAME.
C
      TFX = FYTOT*X(NPTS)/R(NPTS)                 AFTX + PFX
      TFY = FYTOT*Y(NPTS)/R(NPTS)                 AFTY + PFY
      TFZ = FYTOT*Z(NPTS)/R(NPTS)                 AFTZ
C
C  FTX(NPTS), FTY(NPTS), FTZ(NPTS), ARE THE COMPONENTS OF THE RESULTANT
C  SOLAR RADIATION FORCE ACTING ON THE WHOLE BODY OF THE HELIOS SPACECRAFT,
C  ALONG THE AXES OF THE EQUATORIAL, SPACE-FIXED, BODY-CENTERED REFERENCE FRAME.
C
      FTX(NPTS) = TFX
      FTY(NPTS) = TFY*CE - TFZ*SE
      FTZ(NPTS) = TFY*SE + TFZ*CE
C
C  THE MAGNITUDE OF THE RESULTANT SOLAR RADIATION FORCE, IN E-06 NEWTONS, IS
      FTMAG(NPTS) = SQRT(FTX(NPTS)**2 + FTY(NPTS)**2 + FTZ(NPTS)**2)
C
```

```
C   THE ACCELERATION OF THIS FORCE IN E-11 KM/SEC**2 IS
       TACC(NPTS) = 100.*FTMAG(NPTS)/MASS
C
C   TOTAL FORCE IN THE SPACECRAFT-SUN DIRECTION
C
       TDOT = FTX(NPTS)*XQ(NPTS) + FTY(NPTS)*YQ(NPTS)
      *  + FTZ(NPTS)*ZQ(NPTS)
       TFY1(NPTS) = -TDOT/R(NPTS)
C
C   LATERAL FORCE IN THE DIRECTION PERPENDICULAR TO THE SUN-SPACECRAFT
C   DIRECTION
C
       XEQ = XE(NPTS)
       YEQ = YE(NPTS)*CE
       ZEQ = YE(NPTS)*SE
       RRE = X(NPTS)*XE(NPTS) + Y(NPTS)*YE(NPTS)
       DNM = UR(NPTS)*SIN(PSI(NPTS))*R(NPTS)**2
       X1X = (RRE*XQ(NPTS) - XEQ*R(NPTS)**2)/DNM
       X1Y = (RRE*YQ(NPTS) - YEQ*R(NPTS)**2)/DNM
       X1Z = (RRE*ZQ(NPTS) - ZEQ*R(NPTS)**2)/DNM
       FLAT(NPTS) = (X1X*FTX(NPTS) + X1Y*FTY(NPTS) + X1Z*FTZ(NPTS))/
     1    FTMAG(NPTS)
C
C   AVERAGE VALUE OF THE FORCE AT 1.0 AU
C
       FAV(NPTS) = TFY1(NPTS)*RHO(NPTS)**2
       AVTOT = AVTOT + FAV(NPTS)
C
     1 CONTINUE
       AVTOT = AVTOT/N
       WRITE(6,200)
   200 FORMAT(1H1,25(/),25X,-COMPONENTS OF THE SOLAR RADIATION FORCE -
     1   -ACTING ON THE MAIN BODY OF THE -/,25X,-HELIOS SPACECRAFT IN -
     2   -THE SPACE-FIXED EQUATORIAL, BODY-CENTERED -
     3                                 -REFERENCE SYSTEM.-/,25X,-FORCE -
     4   -GIVEN IN E-06 NEWTONS-//)
       DO 201 NPTS=1,N
       DO 202 LIST=1,NP
       LL = 50*(LIST-1)+1
       IF(NPTS.EQ.LL)WRITE(6,203)
   203 FORMAT(1H1,1X,-TIME-,6X,-X(KM)-,9X,-Y(KM)-,9X,-Z(KM)-,9X,
     1   -RHO(AU)-,8X,-XFORCE-,8X,-YFORCE-,8X,-ZFORCE-,8X,-SEP(D)-/)
   202 CONTINUE
       WRITE(6,204)TIME(NPTS),XQ(NPTS),YQ(NPTS),ZQ(NPTS),RHO(NPTS),
     1   BFX(NPTS),BFY(NPTS),BFZ(NPTS),DSEP(NPTS)
   204 FORMAT(F7.2,3E14.6,F12.6,4F14.6)
   201 CONTINUE
       WRITE(6,205)
   205 FORMAT(1H1,25(/),25X,-COMPONENTS OF THE RESULTANT SOLAR RADIATION-
     1   ,- FORCE-/,25X,-ACTING ON THE WHOLE BODY OF THE HELIOS SPACE-,
     2   -CRAFT-/,25X,-ALONG THE AXES OF THE EQUATORIAL, SPACE-FIXED,-
         - BODY-CENTERED-/,25X,-REFERENCE FRAME, THE MAGNITUDE OF THE -,
     4   -RESULTANT FORCE,-/,25X,-AND ITS ACCELERATION.-/,25X,-FORCE -,
     5   -IN E-06 NEWTONS-/,25X,-ACCELERATION IN E-11 KM/SEC**2-/)
       DO 296 NPTS=1,N
       DO 297 LIST=1,NP
       LL = 50*(LIST-1) + 1
       IF(NPTS.EQ.LL)WRITE(6,298)
   298 FORMAT(1H1,-TIME-,5X,-PSI(D)-,4X,,-RHO(AU)-,8X,
     1   -FXEQU-, 9X,-FYEQU-, 9X,-FZEQU-, 9X,-FORCE-, 9X,-ACCEL-,9X,
     2   -FY1-,11X,-FLAT-/)
   297 CONTINUE
       WRITE(6,299)TIME(NPTS),DPSI(NPTS),RHO(NPTS),
     1   FTX(NPTS),FTY(NPTS),FTZ(NPTS),FTMAG(NPTS),TACC(NPTS),
     2   TFY1(NPTS),FLAT(NPTS)
   299 FORMAT(F6.1,F10.2,F11.7,7F14.5)
   296 CONTINUE
```

```
C
      STOP
      END


      FUNCTION ANOM(ECC,M)
C
C   THIS FUNCTION SUBROUTINE SOLVES THE KEPLER-S EQUATION BY ITERATIONS
C
      REAL M
      DATA EPS/.000005/
      ANOM = M
    2 ANOM = M + ECC*SIN(ANOM)
      TEST = ANOM - M - ECC*SIN(ANOM)
      IF(ABS(TEST).GT.EPS)GO TO 2
      IF(ABS(TEST).LE.EPS)RETURN
      END


 $INPUT
 EPSF = 0.74
 EPSB = 0.50
 GAMSA = .65
 GAMCC = .85
 GAMAN = .95
 BETA = .95
 ABETA = .85
 SIGMA = 5.6697E-08
 SOLAR = 1.353E+03
 COND = 0.25
 DEPTH = 0.01
    HA = 2.095
    RA = .03125
 ECC = .521807390542
 ECCE = 0.01672
 TSTART = 0.0
 TSTEP = 86400.
 AX = .96801973563E+08
 AXE = 0.1495989194E+9
 EPSLN = 23.44578889
 OMEGA = 257.444908784
 EOMEGA = 102.50966
 INCL = 23.4469891399
 NODE = .0613804058997
 MESTRT = 340.7615
 MZERO = 71.6320412103
 TLNCH = -5.
 AU = .1495978930E+9
 GM = .13271249939080250OE+12
 MASS = 356.9
 N = 40
 IXX = 343.8
 IYY = 199.8
 IZZ = 382.4
 NORM = 90.,90.,135.,135.,135.,180.,180.,135.,90.,180.,225.,225.,225.,
 180.,270.,225.,270.,270.,315.,315.,315.,323.,0.,0.,36.,45.,45.,45.
 AREA = 140.,22.,160.,156.,156.,140.,65.,19.,20.,20.,160.,156.,156.,65.,
 140.,19.,20.,22.,160.,156.,156.,95.,140.,38.,95.,160.,156.,156.
 $END
-FIN                                                                NIF-
```

APPENDIX 2

Components of the Solar Radiation Force in the Earth-Equatorial Coordinate System of 1950.0 and its magnitude, given in 10^{-6} Newtons.

TIME	FX	FY	FZ	FORCE
5.0	-4.47125	-22.94794	-9.95092	25.40907
6.0	-4.17443	-23.03033	-9.98679	25.44716
7.0	-3.87685	-23.11721	-10.02461	25.49369
8.0	-3.57808	-23.20862	-10.06440	25.54867
9.0	-3.27778	-23.30461	-10.10617	25.61217
10.0	-2.97557	-23.40525	-10.14996	25.68426
11.0	-2.67106	-23.51060	-10.19580	25.76504
12.0	-2.36386	-23.62075	-10.24372	25.85462
13.0	-2.05357	-23.73577	-10.29375	25.95314
14.0	-1.73976	-23.85576	-10.34594	26.06075
15.0	-1.42201	-23.98080	-10.40032	26.17762
16.0	-1.09986	-24.11099	-10.45693	26.30394
17.0	-.77284	-24.24642	-10.51583	26.43991
18.0	-.44047	-24.38720	-10.57704	26.58577
19.0	-.10230	-24.53339	-10.64060	26.74173
20.0	.24235	-24.68516	-10.70659	26.90812
21.0	.59396	-24.84259	-10.77504	27.08521
22.0	.95314	-25.00579	-10.84598	27.27331
23.0	1.32050	-25.17486	-10.91949	27.47276
24.0	1.69671	-25.34992	-10.99559	27.68393
25.0	2.08254	-25.53112	-11.07436	27.90728
26.0	2.47857	-25.71849	-11.15581	28.14314
27.0	2.88568	-25.91219	-11.24001	28.39202
28.0	3.30470	-26.11234	-11.32702	28.65444
29.0	3.73644	-26.31901	-11.41686	28.93088
30.0	4.18204	-26.53240	-11.50962	29.22206
31.0	4.64243	-26.75258	-11.60533	29.52857
32.0	5.11870	-26.97966	-11.70404	29.85109
33.0	5.61211	-27.21379	-11.80582	30.19046
34.0	6.12371	-27.45497	-11.91066	30.54733
35.0	6.65497	-27.70336	-12.01864	30.92269
36.0	7.20735	-27.95905	-12.12979	31.31751
37.0	7.78232	-28.22208	-12.24414	31.73278
38.0	8.38179	-28.49262	-12.36176	32.16981
39.0	9.00747	-28.77068	-12.48265	32.62978
40.0	9.66133	-29.05630	-12.60683	33.11407
41.0	10.34561	-29.34956	-12.73434	33.62427
42.0	11.06239	-29.65038	-12.86514	34.16187
43.0	11.81430	-29.95880	-12.99925	34.72878
44.0	12.70038	-30.28206	-13.13982	35.36888
45.0	13.53340	-30.60974	-13.28232	36.00735
46.0	14.41022	-30.94511	-13.42818	36.68201
47.0	15.33441	-31.28805	-13.57734	37.39559
48.0	16.30933	-31.63823	-13.72966	38.15069
49.0	17.33924	-31.99542	-13.88504	38.95061
50.0	19.51035	-32.90291	-14.27910	40.83073
51.0	20.65375	-33.33328	-14.46628	41.79663
52.0	21.86118	-33.77050	-14.65646	42.81553
53.0	23.13800	-34.21344	-14.84915	43.89104
54.0	24.48956	-34.66048	-15.04366	45.02665
55.0	25.92231	-35.10989	-15.23923	46.22666
56.0	27.44345	-35.55957	-15.43496	47.49594

TIME	FX	FY	FZ	FORCE
57.0	29.06025	-36.00676	-15.62966	48.83924
58.0	30.70111	-36.44829	-15.82195	50.26220
59.0	32.61525	-36.88033	-16.01018	51.77102
60.0	34.57281	-37.29831	-16.19236	53.37261
61.0	36.66475	-37.69670	-16.36612	55.07445
62.0	38.90392	-38.06904	-16.52865	56.88553
63.0	41.30292	-38.40737	-16.67650	58.81465
64.0	43.87747	-38.70243	-16.80567	60.87316
65.0	46.64296	-38.94292	-16.91125	63.07223
66.0	49.61669	-39.11539	-16.98744	65.42479
67.0	52.81820	-39.20382	-17.02728	67.94578
68.0	56.26734	-39.18886	-17.02240	70.65085
69.0	59.98636	-39.04736	-16.96276	73.55810
70.0	63.99814	-38.75136	-16.83625	76.68695
71.0	68.29344	-38.11689	-16.56309	79.94515
72.0	72.95840	-37.56814	-16.32727	83.67122
73.0	77.98418	-36.57659	-15.89957	87.59096
74.0	83.39108	-35.24908	-15.32634	91.82302
75.0	89.19863	-33.51372	-14.57642	96.39521
76.0	95.41834	-31.28482	-13.61265	101.33461
77.0	102.05564	-28.45895	-12.39017	106.67138
78.0	109.10184	-24.91362	-10.85585	112.43553
79.0	116.52925	-20.50495	-8.94729	118.65738
80.0	124.28747	-15.06347	-6.59096	125.37035
81.0	132.28771	-8.39760	-3.70373	132.60571
82.0	140.39789	-.29066	-.19157	140.39832
83.0	148.42263	9.48778	4.04556	148.78058
84.0	156.09394	21.17564	9.11097	157.78699
85.0	165.19121	39.72110	17.15067	170.76313
86.0	171.87850	55.74298	24.09666	182.29138
87.0	177.20855	74.24392	32.11867	194.79897
88.0	179.68071	94.35558	40.84047	207.01709
89.0	178.77514	116.16035	50.29815	219.05178
90.0	173.64509	139.09186	60.24643	230.49684
91.0	163.57350	162.29311	70.31396	240.91367
92.0	148.13131	184.61988	80.00466	249.85622
93.0	127.33431	204.71086	88.72813	256.89150
94.0	100.59042	220.70194	95.67565	260.73283
95.0	71.28720	232.32504	100.73039	263.06539
96.0	39.92726	238.04839	103.22733	262.52067
97.0	8.22108	237.53373	103.01891	259.04199
98.0	-22.14040	231.08393	100.23570	252.85801
99.0	-49.74695	219.55818	95.24964	244.44436
100.0	-73.59985	204.17199	88.58743	234.41603
101.0	-93.81015	186.38685	80.88270	223.79100
102.0	-108.92519	167.31758	72.61894	212.44617
103.0	-124.18117	151.65863	65.83212	206.77324
104.0	-130.38823	133.23985	57.84679	195.19272
105.0	-133.49468	115.68665	50.23542	183.65138
106.0	-134.13596	99.36868	43.15863	172.42174
107.0	-132.89050	84.47775	36.69987	161.68876
108.0	-130.25478	71.08296	30.88933	151.56928

TIME	FX	FY	FZ	FORCE
109.0	-126.63783	59.16347	25.71816	142.12276
110.0	-122.36463	48.64003	21.15216	133.36555
111.0	-117.68828	39.40556	17.14499	125.28878
112.0	-112.79896	31.33529	13.64263	117.86275
113.0	-107.83897	24.30494	10.59125	111.05020
114.0	-102.90939	18.19164	7.93761	104.80594
115.0	-98.08317	12.88381	5.63335	99.08600
116.0	-93.40759	8.27730	3.63333	93.84398
117.0	-88.91478	4.28135	1.89819	89.03803
118.0	-84.62351	.81522	.39292	84.62834
119.0	-80.54194	-2.19267	-.91350	80.57696
120.0	-76.67310	-4.80343	-2.04760	76.85070
121.0	-73.01485	-7.07038	-3.03248	73.41904
122.0	-69.56104	-9.04003	-3.88833	70.25368
123.0	-66.30479	-10.75175	-4.63222	67.33040
124.0	-63.23613	-12.24036	-5.27926	64.62589
125.0	-60.34609	-13.53504	-5.84211	62.12067
126.0	-57.62465	-14.66131	-6.33184	59.79671
127.0	-55.06173	-15.64119	-6.75801	57.63776
128.0	-52.64685	-16.49386	-7.12894	55.62877
129.0	-50.37142	-17.23540	-7.45160	53.75746
130.0	-48.22577	-17.88018	-7.73225	52.01167
131.0	-46.20198	-18.44031	-7.97612	50.38141
132.0	-44.29116	-18.92666	-8.18794	48.85660
133.0	-42.48595	-19.34842	-8.37169	47.42892
134.0	-40.77919	-19.71365	-8.53089	46.09063
135.0	-39.16392	-20.02943	-8.66859	44.83453
136.0	-37.63471	-20.30176	-8.78741	43.65491
137.0	-36.18543	-20.53607	-8.88971	42.54577
138.0	-34.81056	-20.73709	-8.97753	41.50178
139.0	-33.50497	-20.90894	-9.05267	40.51811
140.0	-32.26447	-21.05520	-9.11668	39.59080
141.0	-31.08464	-21.17906	-9.17095	38.71581
142.0	-29.96181	-21.28330	-9.21668	37.88979
143.0	-28.89184	-21.37043	-9.25496	37.10914
144.0	-27.87154	-21.44262	-9.28674	36.37103
145.0	-26.89747	-21.50180	-9.31287	35.67255
146.0	-25.96713	-21.54967	-9.33406	35.01149
147.0	-25.07760	-21.58775	-9.35099	34.38543
148.0	-24.22657	-21.61738	-9.36424	33.79241
149.0	-23.41131	-21.63978	-9.37433	33.23022
150.0	-22.62982	-21.65599	-9.38172	32.69720
151.0	-21.87986	-21.66697	-9.38683	32.19159
152.0	-21.15980	-21.67357	-9.39003	31.71204
153.0	-20.46777	-21.67654	-9.39164	31.25707
154.0	-19.80208	-21.67656	-9.39196	30.82538
155.0	-19.16135	-21.67424	-9.39125	30.41587
156.0	-18.54385	-21.67011	-9.38975	30.02725
157.0	-17.94834	-21.66468	-9.38766	29.65855
158.0	-17.37343	-21.65837	-9.38520	29.30875
159.0	-16.81815	-21.65158	-9.38251	28.97711
160.0	-16.28126	-21.64468	-9.37976	28.66271

TIME	FX	FY	FZ	FORCE
161.0	-15.76170	-21.63797	-9.37710	28.36482
162.0	-15.25861	-21.63175	-9.37463	28.08277
163.0	-14.77084	-21.62629	-9.37249	27.81579
164.0	-14.29760	-21.62183	-9.37078	27.56331
165.0	-13.83805	-21.61858	-9.36958	27.32478
166.0	-13.39141	-21.61674	-9.36899	27.09966
167.0	-12.95682	-21.61650	-9.36909	26.88740
168.0	-12.53378	-21.61802	-9.36994	26.68764
169.0	-12.12150	-21.62146	-9.37163	26.49992
170.0	-11.71937	-21.62696	-9.37420	26.32384
171.0	-11.32676	-21.63465	-9.37772	26.15903
172.0	-10.94310	-21.64465	-9.38223	26.00516
173.0	-10.56792	-21.65708	-9.38779	25.86195
174.0	-10.20052	-21.67204	-9.39446	25.72904
175.0	-9.84047	-21.68964	-9.40226	25.60620
176.0	-9.48729	-21.70997	-9.41124	25.49319
177.0	-9.14050	-21.73313	-9.42144	25.38978
178.0	-8.79965	-21.75919	-9.43290	25.29577
179.0	-8.46431	-21.78825	-9.44566	25.21097
180.0	-8.13406	-21.82039	-9.45975	25.13522
181.0	-7.80848	-21.85568	-9.47521	25.06836
182.0	-7.48717	-21.89421	-9.49207	25.01027
183.0	-7.16975	-21.93605	-9.51036	24.96082
184.0	-6.85584	-21.98127	-9.53012	24.91991
185.0	-6.54500	-22.02996	-9.55139	24.88745
186.0	-6.23701	-22.08218	-9.57418	24.86339
187.0	-5.93144	-22.13801	-9.59853	24.84764
188.0	-5.62800	-22.19751	-9.62448	24.84018
189.0	-5.32618	-22.26080	-9.65206	24.84096
190.0	-5.02574	-22.32791	-9.68131	24.84998
191.0	-4.72627	-22.39897	-9.71227	24.86724
192.0	-4.42754	-22.47400	-9.74495	24.89273
193.0	-4.12912	-22.55313	-9.77940	24.92649
194.0	-3.83078	-22.63639	-9.81565	24.96854
195.0	-3.53202	-22.72392	-9.85376	25.01896

APPENDIX 3

Plots of the Components of the Solar Radiation Force in the Earth-Equatorial Coordinate System of 1950.0, and its magnitude, given in 10^{-6} Newtons.

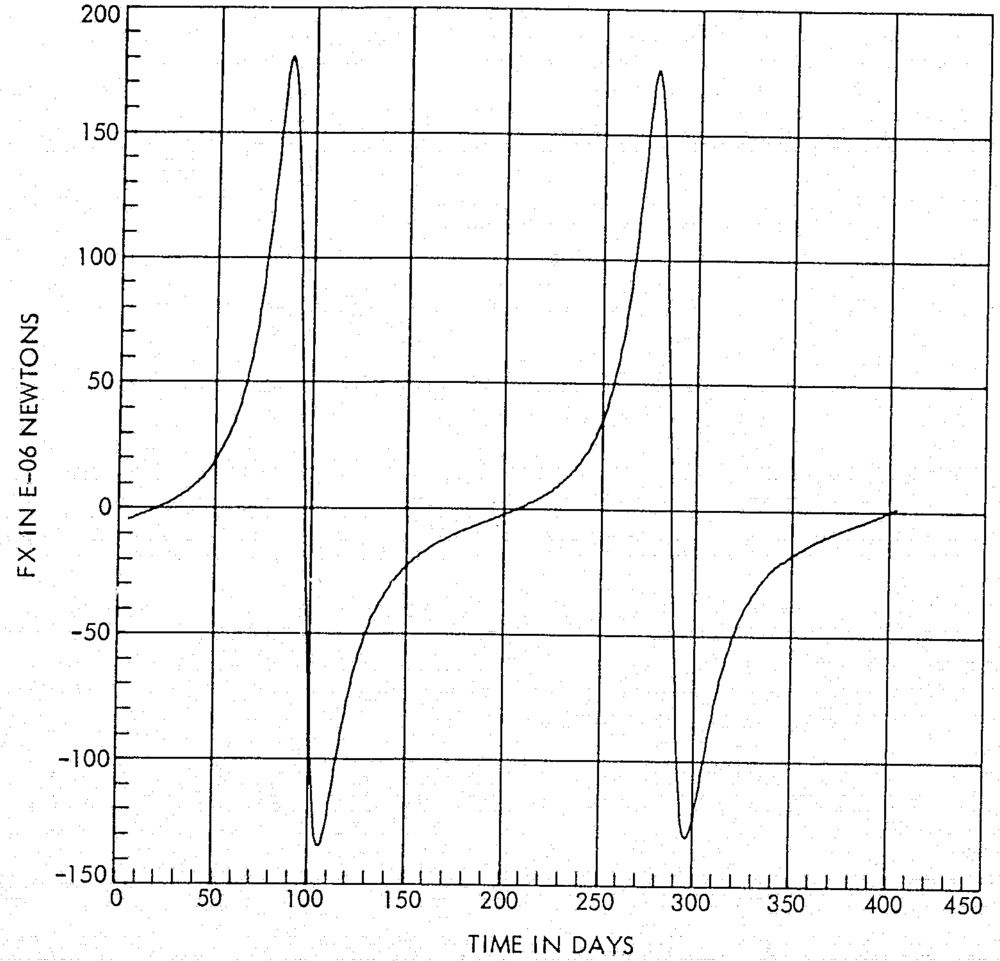

Fig. 3-1. X-component of solar force

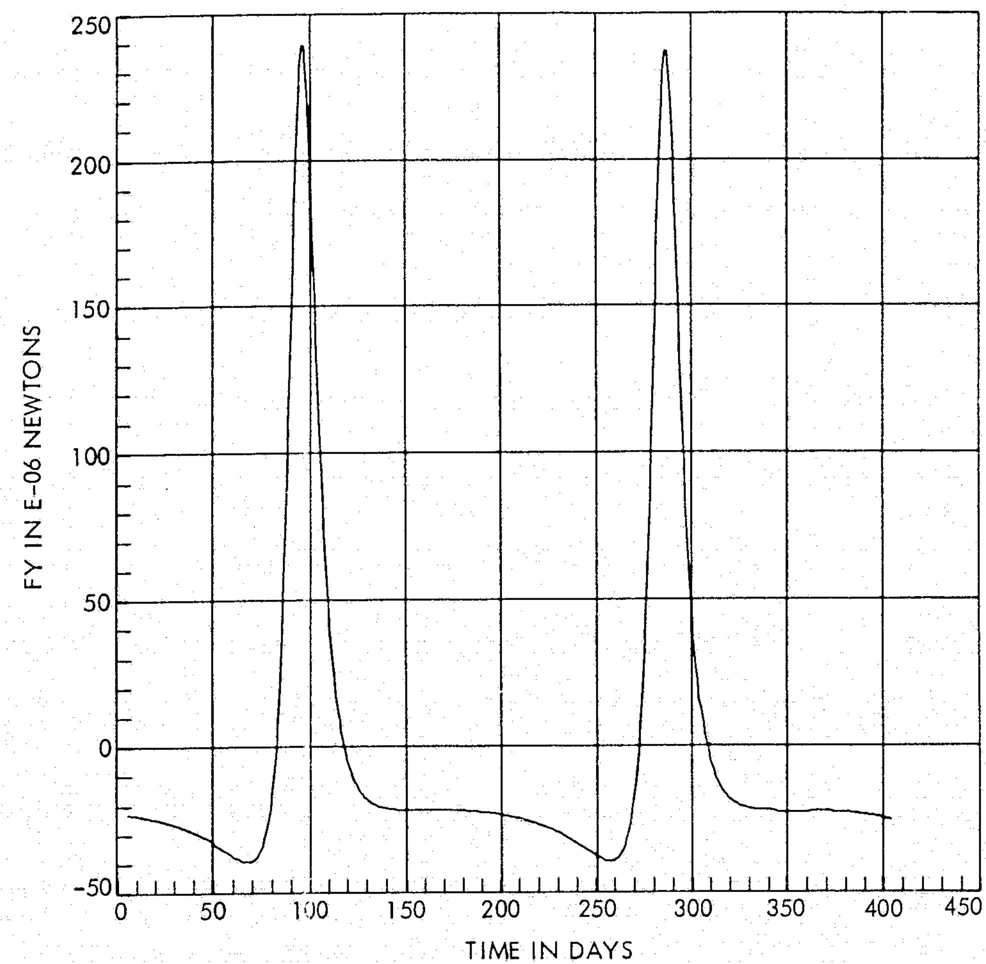

Fig. 3-2. Y-component of solar force

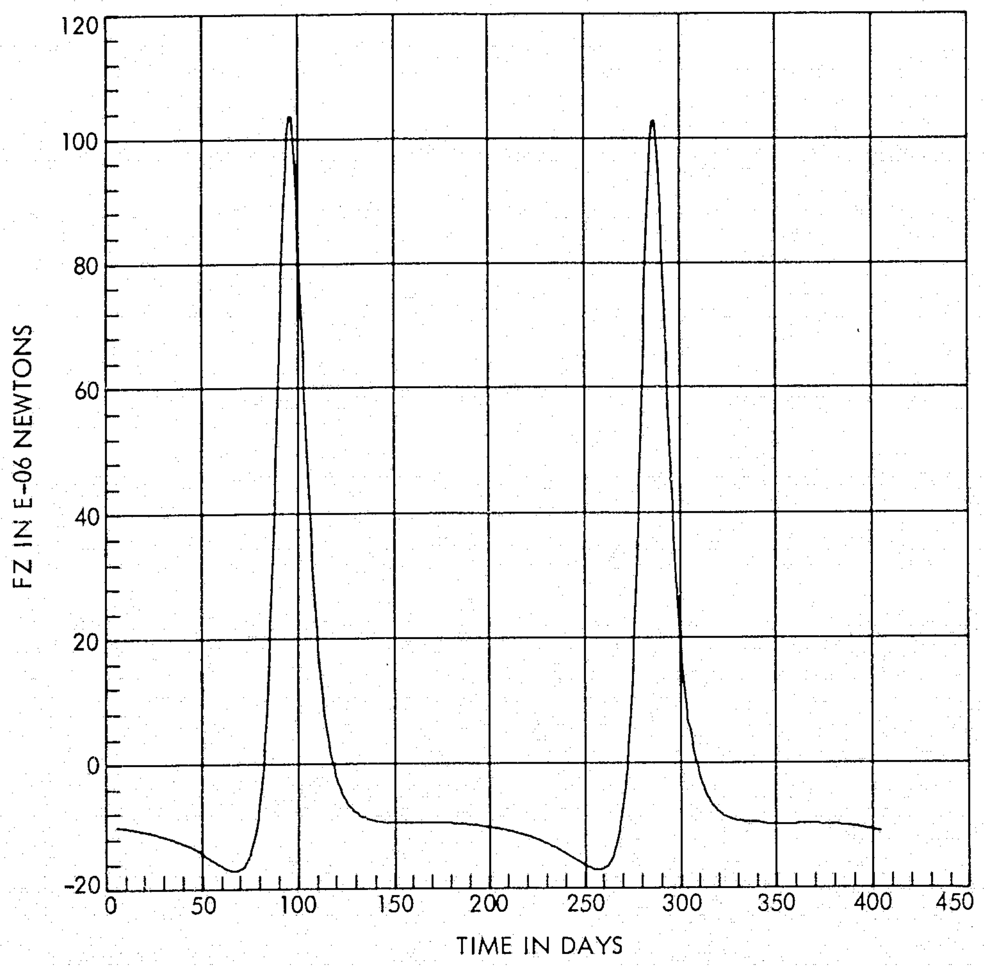

Fig. 3-3. Z-component of solar force

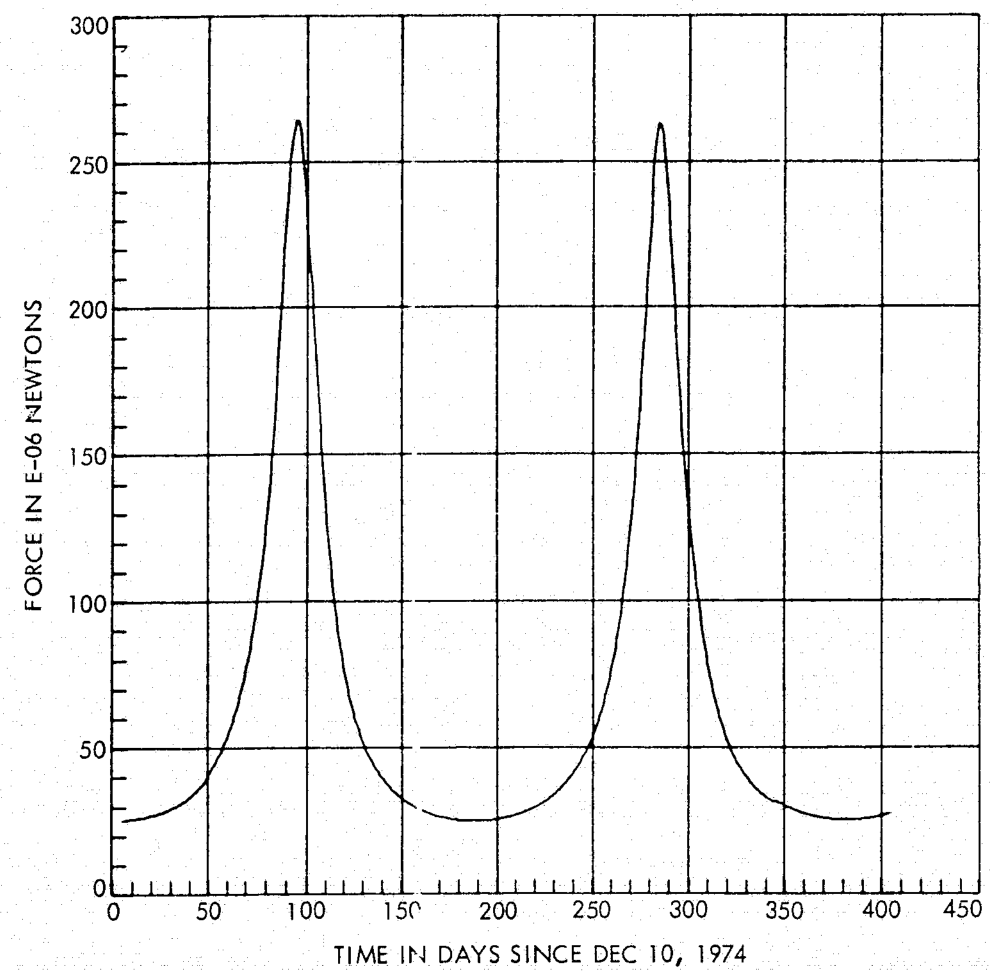

Fig. 3-4. Magnitude of the solar radiation force

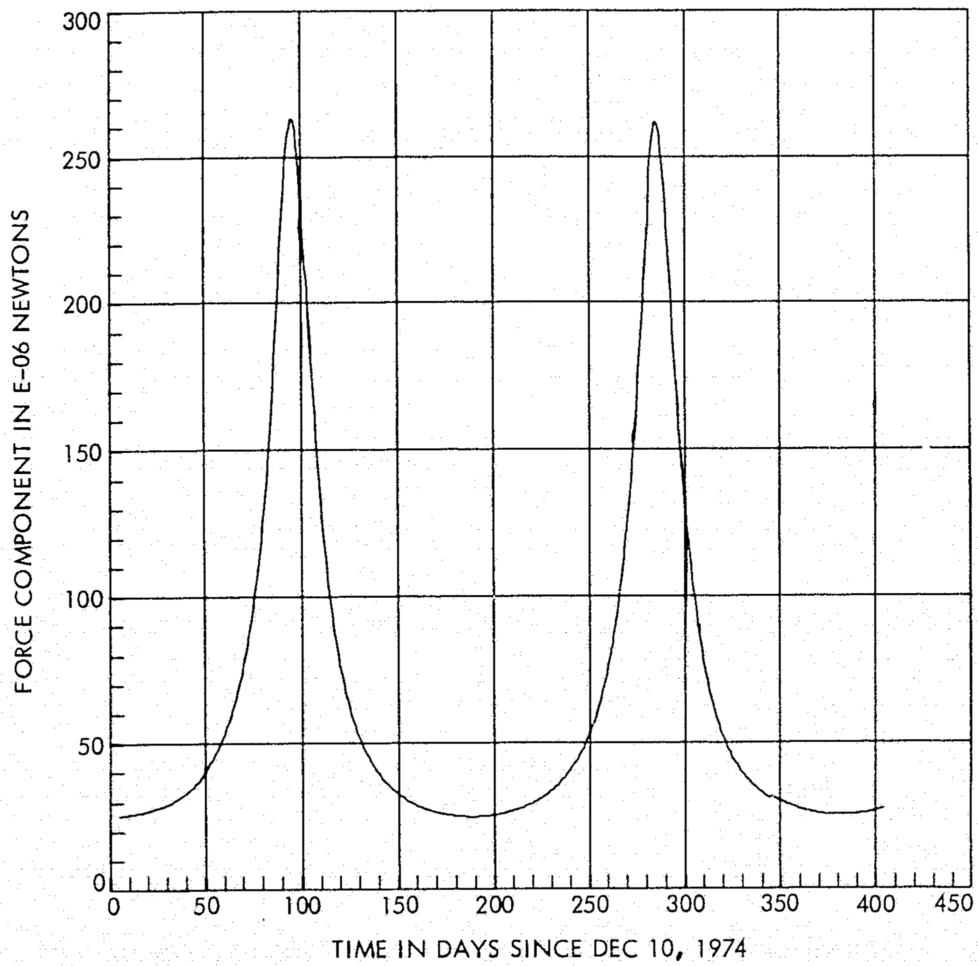

Fig. 3-5. Radial component of the solar radiation force

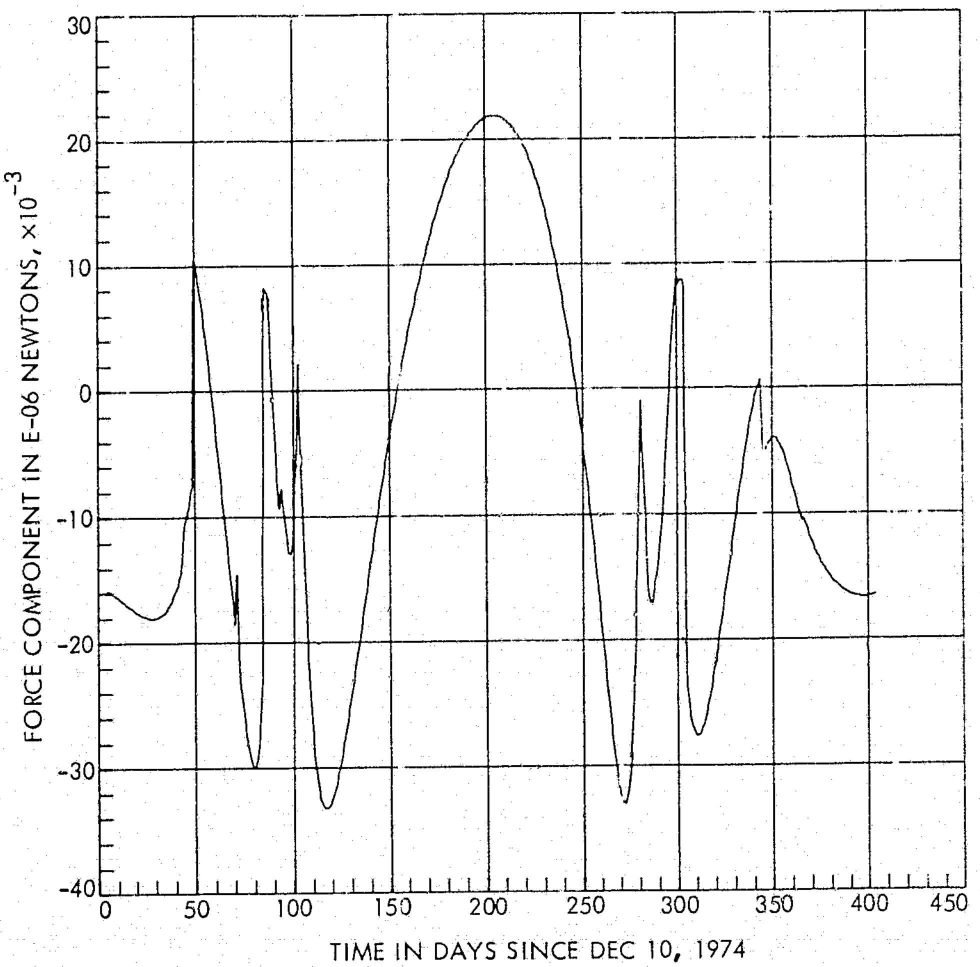

Fig. 3-6. Lateral component of the solar radiation force